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A LAND FORM MAP OF SOUTHERN ALBERTA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled A Land Form Map of Southern Alberta, submitted by Margaret Ann Bullock in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

For most geographical purposes, the configuration of the earth's surface is more relevant than its genesis. An empirical description of the form of the land involves a consideration of the inclination, relief, length, and areal arrangement of individual slopes. Generalisation of these factors is necessary in order to depict the land form on a medium-scale map. Land form classes, each comprising a modal average slope class and a relief per mile square class, are therefore used. In addition to the direct portrayal of values of the consitituent elements, the length of modal slopes and the number of slopes possible in some single-class areas is restricted, and contrasts, in terms of length of modal slopes and nature of non-modal slopes, between areas having one element in common are implied.

A wide range of modal slope and relief values is present in southern Alberta. Mountain and foothill land forms correspond approximately with the geological delineation of the regions. The plains region, however, includes several areas of low hills and hill land. Hill land areas in the west form a transitional zone between the land forms characteristic of the plains and of the foothills.

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CHAPTER I

INTRODUCTION

This study is concerned with the representation of the land form of Alberta, south of latitude 54° N., and with quantitative aspects of its primary and major secondary features. An attempt has been made to portray the appearance of the land form, and, simultaneously, to emphasise characteristics which are of geographic significance. Although the information contained in the accompanying map is the main concern, the latter's production is to some degree exploratory with regard to sources and the utility of the technique to geography.

Land Form Geography

The configuration of the earth's surface is generally regarded as being relevant to geography, but opinions on its degree of significance vary considerably. Wooldridge has stated that "surely the geographer may conclude that morphological analysis [of the form of the land] is fundamental to his final synthesis and value it accordingly."[1] On the other hand, Barrows declared that "[geography] would benefit by frankly relinquishing physiography . . ."[2,3]

[1] S.W. Wooldridge, "The Role and Relationships of Geomorphology," in D. Stamp and S.W. Wooldridge (eds.), London Essays in Geography, London, 1951,pp.19-31.

[2] H.H. Barrows, "Geography as Human Ecology," A.A.A.G., Vol. 13, 1923, pp. 1-14.

[3] The term "physiography" refers to the study of land form.

The point of conflict concerns the relevance of the genetic study of land form to geography, and in this respect, land form geography has suffered by being identified with geomorphology. Thus it has been said that one aspect of physical geography is "concerned with the shape and form of the land surface (that is, physiography or its modern development geomorphology)."[4] Geomorphology, however, is "concerned with the classification, measurement, and description of land forms, and with the history of the processes that have produced them,"[5] and therefore includes both generic and genetic study of the land form. While some would also include both aspects within geography - "the geographer cannot take land-forms as given without intelligent scrutiny of their genesis"[6] - many would be in closer agreement with the statement that "in the majority of cases the processes of change in landforms are so slow that little error results from assuming the landforms as static".[7] Wooldridge, an advocate of the inclusion of genetic studies in geography, nevertheless states that the

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[4]F.J. Monkhouse, The Concept and Content of Modern Geography, Inaugural Lecture, University of Southampton, Southampton, 1955, p. 12.

[5]L. Peltier, "Geomorphology," in P.E. James and C.F. Jones (eds.), American Geography: Inventory and Prospect, Syracuse, 1950, pp. 362-380.

[6]S.W. Wooldridge, "The Progress of Geomorphology," in G. Taylor (ed.), Geography in the Twentieth Century, London, 1960, pp. 165-177.

[7]R. Hartshorne Perspective on the Nature of Geography, Chicago, 1959, p. 85.

geographer "must limit himself to consideration of proximate, not ultimate, genesis."[8] In any instance, the geographer's chief concern in the study of land form is not with its evolution or the detailed investigation of processes, but with the resultant form and, at the most, short-term changes in this form.

Despite this, many geographical descriptions of land form, both verbal and cartographical, are in terms of genesis. To a large extent, this reflects the influence of W.M. Davis, and especially his advocacy of "explanatory description" in terms of origin as the best method of presenting "accurate and intelligible descriptions of the form of the lands."[9] The common subordination of the descriptive to the explanatory element is a change in emphasis at variance with Davis' objective, but inherent in the method. The basic concept that "most explanatory physiographic terms are . . . of fairly definite value," and therefore provide the best means of geographically describing the form of the land,[10] includes several questionable assumptions. To ensure its validity, such terms would have to be narrowly defined, and the

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[8]Wooldridge, "The Role and Relations of Geomorphology," op.cit.

[9]W.M. Davis, "The Systematic Description of Land Forms," Geographical Journal, Vol. 24, 1909, pp. 300-318.

[10]W.M. Davis, "The Principles of Geographic Description," A.A.A.G., Vol. 5, 1915, pp. 61-105.

definitions widely and constantly accepted. Of more importance is the fact that the definitive factors with regard to genesis would have to correspond to those that are significant geographically.

That explanatory description has in many instances failed to meet these requirements is indicated by the criticism directed toward it. Russell, for example, finds many such (geomorphological) landform studies unrealistic, inadequate in the information they supply, and too geological in their interests. With regard to the last assertion, he makes the point that:

> The geomorphologist may concern himself deeply with questions of structure, process, and time, but the geographer wants specific information along the lines of what, where and how much.[11]

A similar conclusion is reached by Kesseli in his statement that much explanatory description is in fact "explanation lacking a description."[12]

A Land Form Map of Southern Alberta

The genetic approach is manifest in almost all existing studies of the land form of southern Alberta. The region is generally divided into the physiographic units of mountains, foothills and plains.[13] Although these are generic land form types, their extent is usually outlined on the basis of

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[11] R. J. Russell, "Geographical Geomorphology," A.A.A.G., Vol. 39, 1949, pp. 1-11.

[12] J.E. Kesseli, "Geomorphic Landscapes," Yearbook, Association of Pacific Coast Geographers, Vol. 12, 1950, pp. 3-10.

[13] J.A. Allan, Geology, Research Council of Alberta, Report No. 34, Edmonton, 1943, p. 12. See Appendix C.

structure, while more detailed subdivision is nearly always in terms of genesis. In contrast, the emphasis in this study is on the empirical description of the land form as a continuous three-dimensional surface. Land form (as two words) is thus a convenient contraction of the phrase "form of the land surface," as compared to the term landform, which refers to a discrete part of this surface, or the idealised conception of such a part.[14]

The relief of a land surface comprises two elements, shape and elevation above a datum plane. Although both may be of importance geographically, the map produced is concerned with the former, as it is local variation in shape, rather than absolute elevation, which characterises the form of the land in any particular area. Basically, this involves the nature (inclination, height and length) and the arrangement of slopes, and their portrayal in such a way that direct comparison can be made between the land form of different areas. At a large scale, contours are undoubtedly the best technique for this purpose. At the scale of the land form map (1: 1,013,760), however, it is necessary to increase the contour interval and to generalise the contours to such a degree that little information of local slope conditions is given. At this and even larger scales, the layer-shading

[14]The terms land form, landform and land-form are used indiscriminately by many writers in reference to either or both of the above meanings. In any citations, the usage of the original is adopted.

(hypsometric tint) technique is usually employed.[15] However, such maps are in a sense contour maps, in so far as the boundary of each "layer" represents a generalised contour, and the same criticism as above therefore applies.

Various pictorial methods are more successful than contour and hypsometric tint techniques in indicating the shape of the land surface at medium and small scales. However, most of these are qualitative, employing pictorial symbols to depict various types of landforms. Moreover, the distinctions made are often based on genetic classifications.[16] To produce such a map, an area must first be classified into discrete landforms, and the appropriate symbols then entered. The result is therefore a portrayal of the location of distinct landforms, rather than of the continuum of surface geometry.

Exceptions to the above are trachographic maps and the similar "proportional relief" map of Ridd.[17] The

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[15] Layer-shading is used on the eight miles to one inch (1: 506,880) maps of the Surveys and Mapping Branch, Department of Mines and Technical Surveys, Canada.

[16] The best known of such maps are those of Raisz and Lobeck. Raisz's "physiographic symbols" are of ideal forms suggested by genetic classification. See E. Raisz, General Cartography, New York, 1948, pp. 120-121. For an example of Lobeck's maps, see A.K. Lobeck, Physiographic Diagram of North America, New York, 1948. This diagram is "based partly upon the Geological Map of North America .... The topographic features shown here harmonize closely with the geological units of North America as shown on the Geological Map."

[17] M.K. Ridd, "The Proportional Relief Landform Map," A.A.A.G., Vol. 53, 1963, pp. 569-576.

trachographic method also employs pictorial symbols, but of a hill-shaped curve whose height and width are proportional to relative relief and average slope respectively. Most methods of producing a three-dimensional effect on a two-dimensional base involve planimetric displacement of features at elevations differing from the datum plane.[18] On Ridd's map, such displacement is proportional to the relative relief above a "local base" for each elevated area, and therefore an accurate visual impression of the relative relief and of the relative average slope of the different features is obtained.

The objective of the thesis, however, is to present such aspects of shape directly in a quantitative manner. None of the above methods achieves this satisfactorily. A better approach is that of analysing the land form into component parts, then synthesising these in the final map. The technique of outlining, on a large-scale map, areas in which the different elements of slope nature (as specified above) have a similar value, and then transfering this information to the final map, was therefore adopted. In this way, at least a portion of the quantitative land form detail of the first map can be retained in the second, although at the

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[18] Most of the methods not involving planimetric displacement are based on contour maps, and thus involve the same problems of generalisation. See, for example, A.H. Robinson and N.J.W. Thrower, "A New Method of Terrain Representation," The Geographical Review, Vol. 47, 1957, pp. 507-520; and K. Tanaka, "The Relief Contour Method of Representing Topography on Maps," The Geographical Review, Vol. 40, 1950, pp. 444-456.

expense of losing the visual impression given by pictorial methods.

With regard to the description of land form, this technique is to be regarded, not as replacing the genetic approach, but as complementing it. As Strahler has pointed out, both methods are valuable.[19] With regard to geography, it represents an attempt to produce, for southern Alberta, the "factual study of landforms" advocated by Russell.[20]

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[19] A.N. Strahler, "Empirical and Explanatory Methods in Physical Geography," Professional Geographer, Vol. 4, 1950, pp. 4-8.

[20] Russell, op.cit.

CHAPTER II

ELEMENTS OF LAND FORM

The map produced portrays the form of the land by indicating, for each area, the value of several component parts. This chapter discusses the theoretical considerations involved in making the map, in contrast to practical considerations such as sources available and specific problems.

Early maps concerned with the morphometry of the land, with a few exceptions,[1] showed only one aspect of the surface geometry. For example, Smith's map of Ohio[2] portrayed relative relief alone, while Raisz and Henry's map of New England[3] depicted only slope inclinations. This is unsatisfactory because there is not necessarily a direct relationship between the angle of slope and the change in elevation (relief) over a wide area. It can be seen in Figure 1 that relief is a function of both angle of slope and length of slope. Considering, for example, slopes whose horizontal length is 3,000 feet: a 10 per cent slope will

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[1]For example, G.B. Cressey, "The Landforms of Chekiang, China," A.A.A.G., Vol. 28, 1938, pp. 259-276.

[2]G.H. Smith, "The Relative Relief of Ohio," The Geographical Review, Vol. 25, 1935, pp. 272-284.

[3]E. Raisz and J. Henry, "An Average Slope Map of Southern New England," The Geographical Review, Vol. 27, 1937, pp. 467-472.

produce a relief of 300 feet, while a 20 per cent slope will produce a relief of 600 feet. If, however, a 10 per cent slope is 6,000 feet long, it also will result in a relief of 600 feet. Neither of the above maps therefore fully describes the surface form. Later studies, however, in addition to the investigation of the logical bases and the comparative effectiveness of portrayal of the different techniques,[4] have produced classifications which combine several elements of land form in order to give a comprehensive representation.[5] That is the aim of the map produced here.

Choice of Elements

Two major restrictions were imposed in selecting the elements to be shown. In the first place, elements visible in the field, rather than abstract derived parameters, are used. Secondly, if a reasonably simple map is to be produced, the number of elements must be kept as low as possible; if many elements were shown on one map, the large number of possible classes can result in numerous small units, making interpretation very difficult. This raises the question of which elements are most significant, and combine most

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[4]See particularly, R.B. Batchelder, "Application of Two Relative Relief Techniques to an Area of Diverse Landform: A Comparative Study," Surveying and Mapping, Vol. 10, 1950, pp. 110-118; W.C. Calef, "Slope Studies of Northern Illinois," Transactions of the Illinois State Academy of Science, Vol. 43, 1950, pp. 110-115; and T.M. Griffiths, A Comparative Study of Terrain Analysis Techniques, Department of Geography, University of Denver, Technical Paper No. 64-2, Denver, 1964.

[5]For example, E.H. Hammond, "Analysis of Properties in Land Form Geography: An Application to Broad-Scale Land Form Mapping," A.A.A.G., Vol. 54, 1964, pp. 11-19; and D.R. Hoy and J.A. Taylor, "A Descriptive Classification of Terrain," unpublished manuscript, 1964.

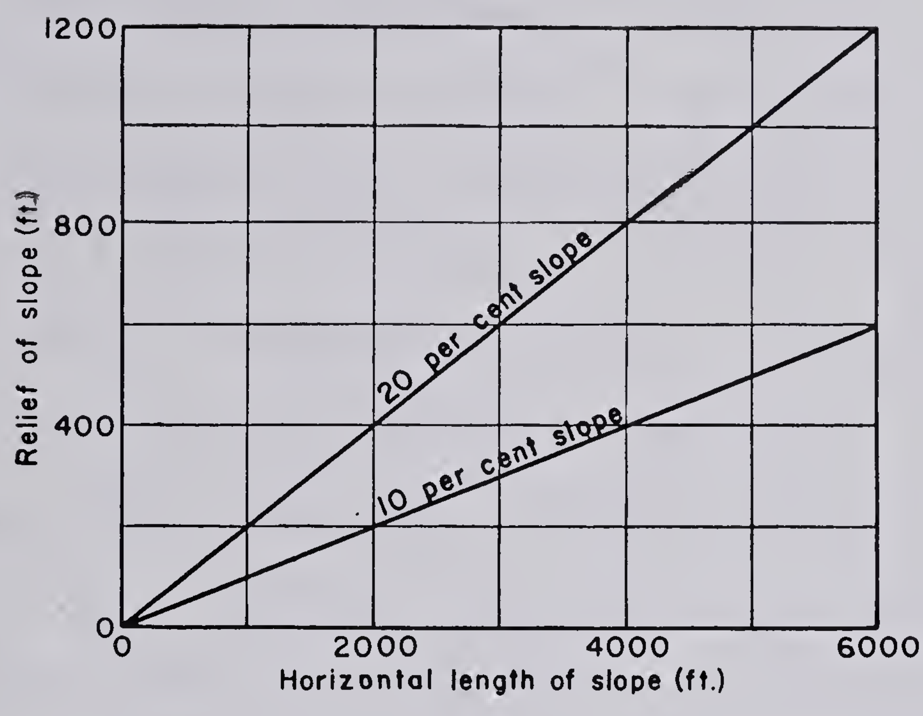

Figure I. Relation of relief of slope to angle and length of slope.

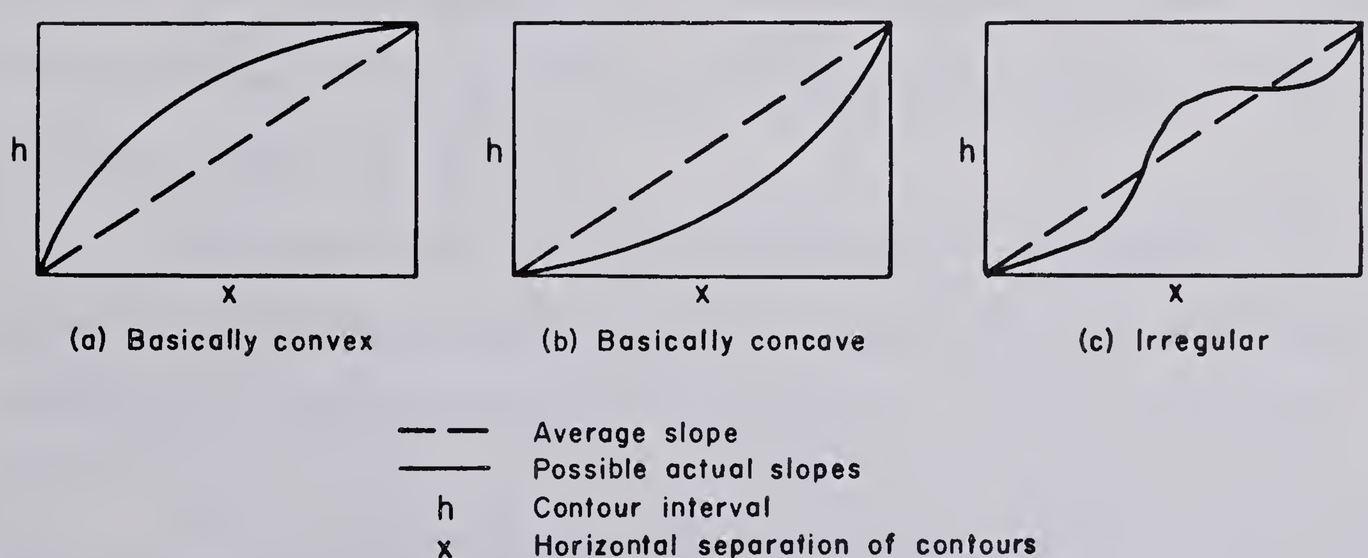

Figure 2. Possible slope profiles between contours.

effectively, in portraying the land form. In a study of the problem, Hammond cited slope, horizontal and vertical dimension, horizontal arrangement of features, and surface material as major characteristics.[6] Salisbury placed the observable dimensions which essentially make up the appearance of a landform into two classes; the external features, comprising relief, inclination of slope, and arrangement of slope; and the internal features, consisting of the composition, arrangement, and structure of materials.[7]

It is the "external features" of Salisbury's classification that are concerned in the description of the form of the land.[8] Considering the above restrictions, slope inclination and relief appear to be the best combination of elements. Angle of slope is of functional significance, especially with reference to land use; relief is of more limited importance in this respect. Slope inclination and relief are individually of visual importance, and together they indicate the geometry of the land surface as they also define length of slope.

The portrayal of the remaining characteristics cited above (horizontal arrangement of features and arrangement of slope) necessitates some indication of slope direction.

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[6]E.H. Hammond, Procedures in the Descriptive Analysis of Terrain, Final Report, O.N.R. Project No. NR 387-015, Madison, Wisconsin, 1958, passim.

[7]N.E. Salisbury, A Generic Classification of the Landforms of Minnesota, (University Microfilms Pub. No. 24, 676) Ph.D. Thesis, University of Minnesota, Minneapolis, 1957 p. 50.

[8]Surface material, although of importance in describing the land surface, is not an element of land form.

However, in a majority of cases, this is not constant enough to be depicted on a map of this scale. The smallest areas that can be shown commonly include numerous individual slopes, which may have any direction. On maps of a larger scale, slope direction has been indicated by arrows pointing downslope,[9] and by a choropleth technique.[10]

In addition to the illustration of the primary features of the land form of southern Alberta, an attempt is made to emphasise the major secondary features; that is, to depict the variations in surface geometry within the mountains, the foothills and the plains. Batchelder, in comparing the effectiveness of maps of slope inclination and maps of relief in portraying the land form, came to the conclusion that the former are more successful in indicating secondary features.[11] Contrasts in slope inclination are therefore indicated by colour on the map.

Slope[12]

Two major theoretical difficulties must be considered in classifying the land form according to angle of slope. The first is that the land surface is, in fact, a continuum

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[9]R.M. Glendinning, "The Slope and Slope-Direction Map," Michigan Papers in Geography, Vol. 7, 1937, pp. 359-364.

[10]R.J. Eyles, "Slope Studies in the Wellington Peninsula," New Zealand Geographer, Vol. 21, 1965, pp. 133-143.

[11]Batchelder, op.cit.

[12]The term slope has two distinct, though related,

of slopes, the inclination of which often changes constantly and imperceptibly. It is therefore necessary to establish classes to show the areal variation of slope inclinations in two dimensions, even at the same scale. But the second problem stems from the fact that the purpose of a map is to show a portion of the earth's surface at a convenient size, and therefore at a reduced scale, so the question of generalisation arises. This occurs with regard to both measuring and mapping the areal extent of slopes. The slope inclinations of any area must be summarised, and it is important to understand the meaning of the "average slope" figure used. A further point is that it is the horizontal rather than the actual extent of slopes which is shown on a two-dimensional map. The area of gentle slopes relative to that of steep slopes is therefore overemphasised visually. This results in the easy portrayal of small but significant areas of gentle inclination in a district of predominantly steep slopes, but makes it difficult, and frequently impossible, to indicate small areas of steep slope.

The above considerations mean that even when slopes are measured directly in the field, an absolutely true representation cannot be produced. Moreover, the process is extremely slow and time-consuming, and has generally been used only in large-scale studies of small areas, often with

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meanings. It may refer to an inclined surface, or to the angle in which the surface intersects a horizontal plane. It is used in either or both senses in the following pages, and the meaning is specified if not clear from the context.

the objective of studying slope development.

Most medium and small scale maps of slope inclination have been based instead on figures derived from contour maps. The perpendicular distance between any two contours on the map represents the horizontal distance between the two points on the ground, and the tangent of the angle of the intervening slope can thus be obtained by dividing this value into that of the vertical separation of the two contours. This immediately involves some degree of generalisation, even with an accurate, reliable map, since the assumption is made that the surface slopes directly and uniformly from the horizontal position of one contour to that of the next. It can be seen in Figure 2, however, that the slope between contours may be concave or convex, and is in fact in the majority of cases, irregular. Furthermore, as the distance, either horizontal or vertical, included in the computation is increased, the discrepancy between calculated and real slope values is likely to become greater. Despite this, the inclination thus acquired is what is usually termed "average slope."

Several workers prior to 1930 evolved mathematical formulae for finding the average slope of a small area.[13]

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[13]For example, J.L. Rich, "A Graphic Method of Determining the Inclination of a Land Surface from a Contour Map," Transactions, Illinois Academy of Science, Vol. 9, 1916, pp. 195-199; and C.K. Wentworth, "A Simplified Method of Determining the Average Slope of Land Surfaces," American Journal of Science, Series 5, Vol. 20, 1930, pp. 184-194.

These too were related to contour spacing, but attempted to derive a measure of average slope over any distance, in contrast to the average value of one particular slope. Wentworth's formula, for example, enables the average slope to be calculated along any transect line, regardless of its angle of intersection with the contours. Nevertheless, using the Wentworth formula per se, Calef concludes that "the concept of average slope is meaningful only insofar as the majority of slopes in an area have some approximation to the average slope."[14] This condition is certain to be fulfilled only in areas of extreme slope class. For example, if the average slope is less than 5 per cent, a large part of the area must have inclinations less than or about 5 per cent. In areas of intermediate class, however, situations similar to the following case encountered by Calef may occur: a series of cuestas has scarp slope inclinations of the order of 10 per cent, while the remaining slopes have inclinations of less than 1 per cent. The average slope for the area, calculated by Wentworth's formula, is 3 per cent. This places the area in the "1 to 5 per cent" slope class on Calef's map, yet no slopes with such inclinations are actually present.[15]

In much of the plains region of Alberta, the assumption that the actual slope between contours approximates the

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[14]Calef, "Slope Studies of Northern Illinois", <u>op.cit.</u>

[15]W.C. Calef and R. Newcomb, "An Average Slope Map of Illinois," <u>A.A.A.G.</u>, Vol. 43, 1953, pp. 305-316.

average slope is completely invalid. In most areas, the contour interval of available maps far exceeds the height of individual slopes, and the position is therefore similar to that shown in Figure 2(c). The problem has been expressed by Strahler who says that "where individual landforms are small in relation to the contour interval, countless surface inflections are not mapped, and the map becomes a uselessly-generalized envelope."[16]

The plains are therefore a problem area in that values of average slope in the usual sense are meaningless; they represent the regional rather than actual slopes. A figure such as the modal slope value appears preferable. The mode is defined as "the value of a class within a statistical group in which there are most instances."[17] Thus the modal (average) slope class is that within which a majority of slope inclinations of an area lie. This is not completely satisfactory, since there is often no rise to a well-defined maximum, and only 50 per cent or so of an area may actually have inclinations within the modal average slope class. Nevertheless, there is the advantage that inclinations within the modal range do occur, and occupy a greater area than inclinations of any other single class. Thus, presumably, such slopes are a factor in the characteristic appearance of the land form. For much

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[16]A.N. Strahler, "Quantitative Slope Analysis," Bulletin, Geological Society of America, Vol. 67, 1950, pp. 571-596.

[17]S. Gregory, Statistical Methods and the Geographer, London, 1963, p. 7.

of the plains region, therefore, the slope values shown are those of the topographic classes of the Alberta Soil Survey, as these are based on figures approximating modal slope values.

In dealing with the remaining regions of the area, however, slope values were derived from contoured maps. In areas of greater relief (both absolute, and, more importantly, with regard to the contour interval available), average slope in the usual sense is more meaningful, with the reservations discussed above. Individual slopes are depicted by the contour pattern, although the detailed form between contours is not indicated. Thus the average slope value between successive contours was used in these areas. This too might be called a modal average slope, though in a slightly different sense from that used earlier, since small areas of different average slope were ignored. The modal value concerned here, however, is of the average slope between contours, in contrast to the modal average of actual slope inclinations.

A further problem relating to the need for generalisation is that of delineating areas to be shown as units. Many maps have been based on the use of a grid system. The chief advantage of this is its comparative objectivity and reproducibility if a formula such as Wentworth's is used to obtain the average slope of each unit area. If the objective is to depict slope conditions as realistically as possible, however, this is outweighed by its disadvantages. The principal disadvantage of a grid system, as Thoman has pointed out, is that "variations clearly visible on topographic

sheets or in the field may be either suppressed or the boundaries may be distorted."[18] Thisis especially true in the plains region, where areas of steeper slope, though important elements in the land form locally, are often small in extent. An extremely fine grid would be necessary to show existing conditions effectively, and map compilation would become proportionately time-consuming. In a detailed field investigation of an area of similar land form (Minnesota), Salisbury found that even 10 acre squares were too large to "present slope-relief relationships in as homogeneous a manner as possible," and finally made use of squares only 2.5 acres in area.[19] With reference to Alberta, a larger area chosen at random could include, for example, some ground moraine, some hummocky disintegration moraine and some erosional slopes. The different inclinations typical of these landforms would be neutralised in an "average slope" figure, while it is conceivable that no one class value would predominate sufficiently to give a single modal maximum. Many landforms, such as minor river valleys, though large enough in extent to be shown on the land form map if viewed as a unit, could be lost by virtue of their being included in the modal average slope figure of several adjacent squares if a grid were used. The same argument applies with regard to the portrayal of small areas of gentle slope in the

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[18] R. Thoman, "A Method of Constructing Average Slope Maps," Transactions, Illinois Academy of Science, Vol. 45, 1952, pp. 82-84.

[19] Salisbury, op.cit., p. 53.

mountain and foothill regions of Alberta.

Where there are well-defined boundaries between terrain types, subjective delimitation is "superior in that such divisions can be precisely located on the final map."[20] Slope inclinations, however, commonly change gradually, in a transitional zone. At the scale of the land form map, many such transitional areas are included in the width of a line. Even where this is not the case, it is doubtful whether the use of a grid would result in a more accurate representation, as boundaries would vary depending on the relative position of the grid and the terrain map. For the above reasons, slope areas were outlined subjectively.

Several authors have reached similar conclusions regarding the use of a grid. Raisz and Henry, working in New England, decided that the topography was too complex to be shown effectively if a grid were used. They proceeded to outline areas of similar slope by eye on contoured maps, then calculated the average slope of each area, and thus established a classification.[21] The method used here is a slight variation on this, in that the classification was established first, and areas then outlined accordingly. Precisely the same method has been used by Batchelder, as by this technique "subjective reasoning was limited to the

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[20]Thoman, op.cit.

[21]Raisz and Henry, op.cit.

selection of the average slope intervals and the degree of proficiency attained in applying the guide."[22] Selection of areas to be shown here was determined primarily by horizontal extent, but the importance of a feature in the landscape was also considered. River valleys, for example, were indicated wherever this was practicable.

Relief

Vertical dimension is the second element used to describe the land form. That this factor is noticeable in the appearance of the land surface is indicated by the common description of a countryside as mountainous, hilly or plain. In the portrayal of relief, as in that of slope, problems of classification and generalisation are present. The question regarding what is to be shown as "relief" arises. In the field, relief is recognised very generally in the sense alluded to above, or in fine detail as the height of individual slopes. The map, however, is at an intermediate scale where perception of relief in the first sense is too generalised, and in the second too detailed. Furthermore, considering the sources available, it is impossible to show the modal or mean individual slope height (which would be the most desirable solution) without first collecting the data

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[22]Batchelder, op.cit.

in the field.

"Local relief," defined here as the difference in elevation between the maximum and minimum heights of an area one mile square, appears the best compromise. In the plains region, such an area is small enough to negate the influence of any regional slope to a large extent, while the full length of many slopes in other regions is included. The local relief of an area one mile square therefore approximates the height of individual slopes. Since the highest and lowest points are not necessarily visible simultaneously in the field, local relief is a more abstract parameter than an index of individual slope heights, but it is commonly employed, and has the advantage that it can be obtained rapidly and satisfactorily even from less reliable data.[23]

The problem of outlining areas to be shown as units applies to relief as to slope. The same arguments can be cited regarding the use of a grid, in that natural land form units may be divided among several squares, resulting in a false representation of relief. Since division based on slope inclination best serves the purpose of the map, the same boundaries are used to delineate the areas within which local relief was calculated. However, to enable comparisons to be made, the local relief of a constant area must be shown.

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[23]Calef, "Slope Studies of Northern Illinois," op.cit.

The area should be of a size which includes the full length of typical slopes, yet whose local relief is not influenced primarily by any regional slope. Slopes vary greatly in length in southern Alberta, but a square one mile by one mile is most suitable. Instead of placing such squares as a fixed systematic grid in each outlined area, a single square was laid in many different positions, and the most frequently occuring relief class was then assigned to the whole area.[24] By using this technique the disadvantages of a systematic grid were overcome, and the effect of any large areas of non-modal inclination reduced.

Where marked differences in local relief occur within an area of similar slope inclinations, they are indicated on the map where practicable. The use of a movable square enabled such boundaries to be drawn as daysmetric lines. More frequently, however, the converse is true, and adjacent areas of different slope class have the same local relief.

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[20]Bunge suggests the possibility of combining the advantages of random and systematic sampling to some extent by locating a systematic grid in different positions and orientations within an area, and regarding each reading as one point. This is, in effect, similar to the procedure outlined above. See, W. Bunge, Theoretical Geography, Lund Studies in Geography, Section C, General Mathematical Geography, No. 1, Lund, 1962, p. 99.

CHAPTER III

SOURCES

Slope

The chief sources of information concerning slope inclination for compiling different areas are indicated in Figure 3. In many instances, however, other sources were used to check the position of boundaries shown on the map. These sources are discussed below.

Topographic Maps

It has been stated that there is no rival to an accurate contour map for purposes of measuring slope.[1] This is not strictly true in parts of Alberta, but nevertheless, topographic maps were the only source referred to throughout the area. The largest map generally available is on a scale of 1:50,000. The coverage and contour interval of such maps which had been published at the time of map compilation are shown in Appendix A. The contour interval is 25 or 50 feet in the plains region, and 100 feet in the mountains. The remaining area is covered at scales of 1:63,360 (one mile to one inch); 1:190,080 (three miles to one inch); and

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[1]E.H. Hammond, Procedures in the Descriptive Analysis of Terrain, Final Report, O.N.R. Project NR387-015, Madison Wisconsin, 1958.

1:250,000. The contour interval on these maps ranges from 50 to 100 feet in the plains, and 200 to 500 feet in the mountain region. Maps having a 10 foot contour interval, at a scale of 1:25,000, are, unfortunately, available only for the areas around Edmonton and Calgary.

The reliability of the maps varies. The 1:25,000 and 1:50,000 maps are generally of recent date, while all the 1:250,000 maps used have been published since 1954; these maps are presumably reliable. Many of the 1:190,080 maps, however, were published in or before the 1920's, and the 1:63,360 map used was published in 1937. The (present) accuracy of these maps is therefore questionable.

Contour maps formed the sole, and a generally adequate, source of slope information for the mountain and most of the foothill regions. Relief here is high, and for much of the area slopes could be delimited satisfactorily on smaller scale maps having a greater contour interval. Thus recent 1:190,080 maps, with contour intervals of 200 and 250 feet, were used for the Jasper and Banff National Park areas respectively. Nonetheless, several boundaries were checked, and areas of gentler inclinations were classified, with the aid of 1:50,000 maps. These maps, having contours at 50 or 100 foot intervals, were also used where available for the remainder of the regions. Such contour intervals, however, while giving an adequate portrayal of steeper slopes, may not accurately represent the detailed form of areas of lower average slope. With this general exception, the only areas

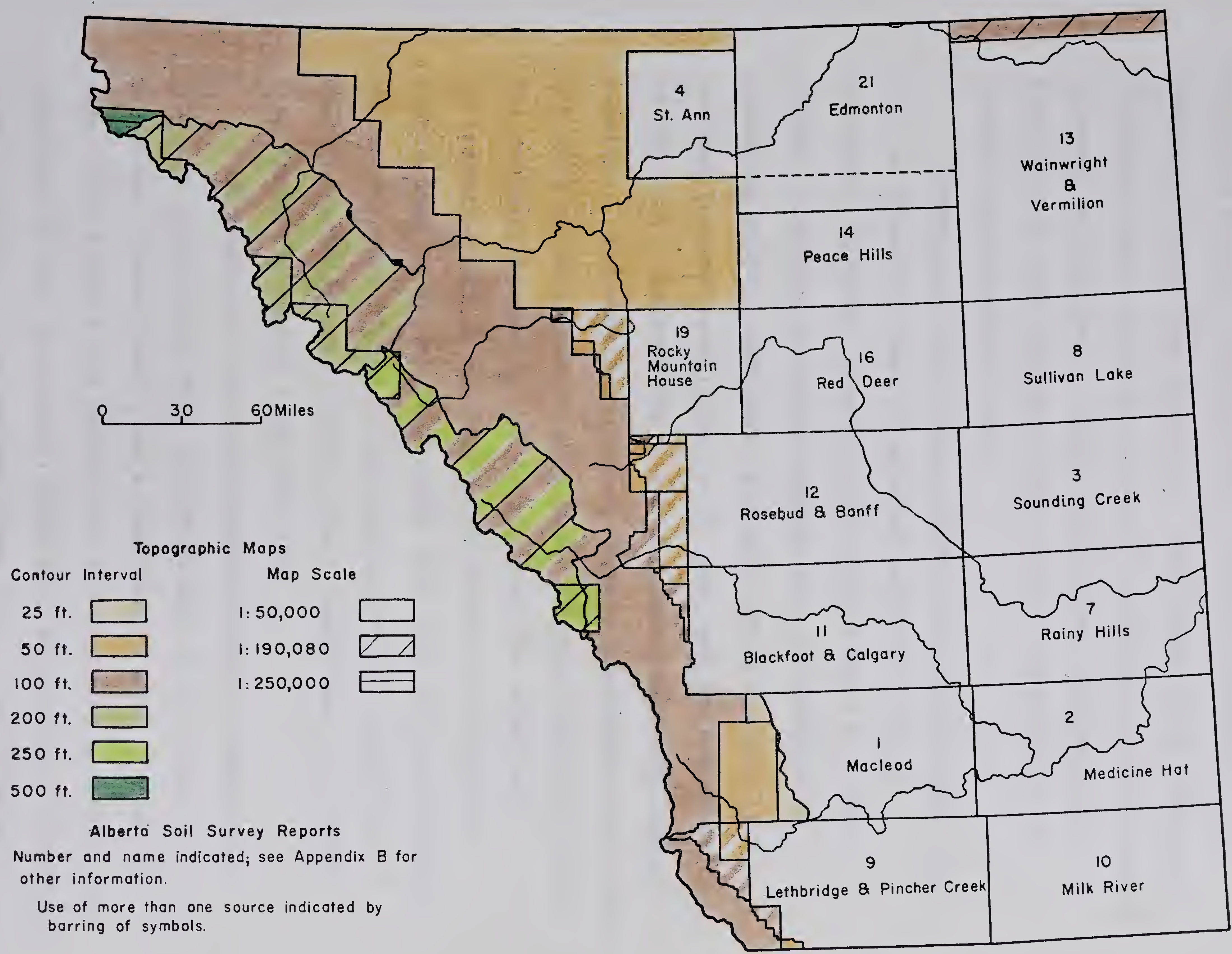

Figure 3. Sources of slope information.

of unsatisfactory coverage occur in the northwest of the mountain region (see Figure 4). The largest map available for these areas is on the scale of 1:250,000, with a contour interval of 500 feet. Slope subdivisions and assigned inclinations may therefore bear little relationship to actual slopes present here.

Throughout the plains region, topographic maps were used to classify areas of steeper and longer slope. Elsewhere, however, even 1:50,000 maps with a 25 foot contour interval are often useless for the purpose of measuring slope. Moreover, for many areas the smallest contour interval available is 50 feet, and in two districts, is 100 feet. Consequently, other sources were used where possible. Nevertheless, in some areas, topographic maps were the most suitable source available. In such instances where the contour interval is 50 or 100 feet the areas are indicated as having unsatisfactory sources in Figure 4. Slopes tend to appear less steep than they are in actuality on contour maps of the plains region, so it is possible that in parts of these areas actual slopes may be steeper than indicated on the land form map.

Although of little use quantitatively, topographic maps, in conjunction with foreknowledge of the types of landforms present, may give a qualitative idea of the land form. The density and pattern of the contours suggests the roughness of the topography, albeit an exaggerated impression might be given if one contour plane chances to intercept

numerous slight swells. The distribution of woodland, lakes and marshes also indicates the general form of the land. Slope boundaries derived primarily from other sources were therefore checked on topographic maps.

Alberta Soil Survey Reports

For much of the plains region, Soil Survey Reports were superior to contour maps as a source of slope information.[2] Topography is indicated on all the soil maps, and is referred to frequently in the text. Topography classes are based primarily on slope inclinations; more particularly, on the most frequently occurring (modal) slope class. As only actual slopes are measured, and any intervening flats ignored, land at the given inclination probably occupies about 50 per cent of the area outlined. Since 1936, eye estimates of slope inclination have been checked, at first with an Abney level, and since 1940 with a Brunton compass. The frequency of checking varies.

The Soil Survey maps are at a scale of 1:126,720 or 1:190,080, the latter being more common in the plains area concerned. The topography classes shown vary with the age of the report.[3] From the beginning "hilly" areas have been differentiated; these generally have modal slope

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[2]The information used in this section, other than that explicit in the soil reports, is by pers. comm. W.E. Bowser, Alberta Soil Survey, Edmonton.

[3]Information concerning individual reports is listed in Appendix B.

inclinations of over 15 per cent. This is the only distinction made with regard to slope on the first (Macleod) sheet, but the number of classes distinguished gradually increased, and four topographic classes are shown on nine of the fifteen maps used. Consistency in the representation of topography is not therefore all that could be desired. This is true also with regard to the names and limits of the topographic classes portrayed. They have the great advantage of being based on work in the field, but this resulted in a "trial and error" development of classification, and consequent changes in detail. As a standard for comparison, the classification employed on the Edmonton sheet (the most recent regular report used in compiling the map) is outlined in Table I.

TABLE I: TOPOGRAPHIC CLASSES: SOIL SURVEY OF THE EDMONTON SHEET

Class	Modal slope (per cent)
Level and undulating	< 5
Gently rolling	5 - 9
Rolling	10 - 15
Hilly	> 15

Of the other fourteen reports, only the Red Deer map has exactly the same classification. On the Peace Hills and Rocky Mountain House sheets, the same terms are employed, but the class limits are defined as: less than 4 per cent; 4 to 8 per cent;8 to 15 per cent; and over 15 per cent. Prior

to this, no quantitative boundaries were given, although the same qualitative classes are used on the five preceding maps. In the two previous sheets, "level, undulating, and gently rolling" topography is included in one class, thus reducing the number of divisions to three. On the four earlier maps, treatment of topography is even less satisfactory. Only "hilly" land is distinguished on the Macleod sheet; this corresponds approximately in slope value with the "hilly" class used later. On the Medicine Hat sheet, a "rolling" category is added below this, while "rolling" and "heavily rolling" land is differentiated on the Sounding Creek sheet. Two classes, "rolling to heavily rolling" and "heavily rolling to hilly," are also shown on the St. Ann sheet. On all fifteen maps, "eroded areas" of steeper slope are indicated, but no quantitative values are given.

The texts of the Soil Reports also confer some knowledge of topography. Organisation varies, but in the older reports a brief description, usually including topography, of each area of the different soil classes is given. This proved particularly useful as the older maps are least satisfactory in the presentation of quantitative aspects of topography.

The chief disadvantage of this source is thus the inconsistency and frequent lack of quantitative definition of the topographic classes. Despite this, Soil Reports were found to be of greater value than contour maps in showing even major variations in slope inclination in the plains region. In a comparision of topographic boundaries at junctions of

soil maps using different nomenclatures there is an exact or very close correspondence in most cases. Moreover, in the area of overlap of the Peace Hills and the Edmonton sheets, the differences in outline between areas over 4 and over 8 per cent on the former, and the areas over 5 and over 10 per cent on the latter, are insignificant when reduced and generalised to the scale of the land form map. It is therefore likely that in spite of the different topographic class names used on various maps, the land forms they describe are similar in terms of slope. However, the quantitative slope limits of the classes are only approximate.

<u>Aerial Photographs</u>

The slope boundaries drawn for the plains region were also checked on air photographs. Although actual slopes can be measured on stereoscopic pairs of photographs,[4] the process is time-consuming, and is best suited for detailed study. Mosaics were therefore used; these are available at a scale of 1:63,360 for the whole area. A general idea of contrasts in land form can be gained from monocular clues. In Alberta, glacial landforms and land use are especially valuable. Bearing in mind that these are not a reflection of slope conditions alone, the correspondence of map divisions with apparent changes in slope inclination was checked.

<u>Other Sources</u>

Other sources mentioning slopes in any detail

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[4]For a discussion of the use of air photographs in small-scale mapping of slopes <u>see</u> Hammond, <u>op.cit.</u>, p. 63 and Appendix I.

are either themselves based on Soil Survey Reports,[5] or are concerned with land classification for irrigation purposes, and therefore provide only detailed subdivision of comparatively level areas.[6]

Adequacy of Sources

Those areas where sources proved unsatisfactory are shown in Figure 4. Most of them occur in the plains region. In the northeast of the region, slope boundaries had to be delimited with the aid of an old 1:190,080 map, having a 100 foot contour interval, and from air photographs alone. Between latitudes 50° 30' N. and 51° 45' N., a narrow area immediately west of 112° W. was also covered by topographic maps with a contour interval of 100 feet. It was also included on the old Sounding Creek and Rainy Hills Soil Reports. Boundaries are also tentative in other areas included in the older Soil Reports where the lowest contour interval available was 50 feet. "Eroded areas" in the southeastern part of the map area had to be classified from a 1:250,000 map with a 100 foot contour interval, although for the remainder of this district the Soil Survey Report proved satisfactory. The remaining areas of inadequate sources are those where contour maps having too great a

[5] Canada, Department of Agriculture, Classification of Land, Sounding Lake Special Area, Alberta, Ottawa, 1938.

[6] Committee of the Canada Department of Agriculture, Land Classification of the Bow River Project, Regina, 1960.

contour interval to show the detailed form of the land were the chief source. This applies particularly to the northwestern part of the plains region, and generally to areas of gentle inclination within the foothills and mountains.

Relief

Since the parameter used to portray vertical dimension is "local relief," values could be derived entirely from contoured topographic maps. The coverage and reliability of topographic maps have already been discussed in connection with slope sources, and the scale and, more important, the contour interval used in different areas is shown in Figure 5. The lowest contour interval available was used except for areas of steep slope in the mountain region. Here it proved equally reliable and far more rapid to estimate local relief from maps having a greater contour interval.

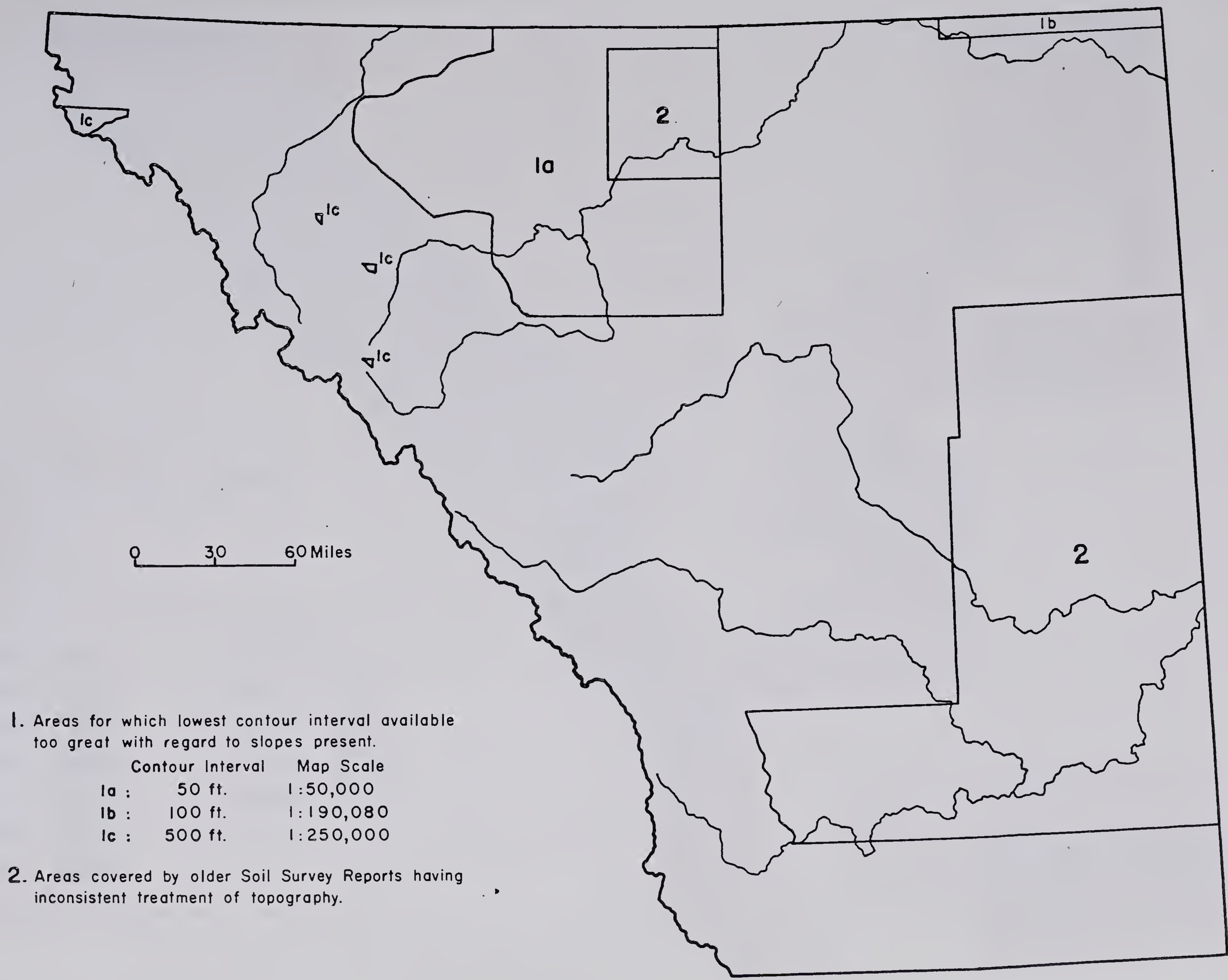

Figure 4. Areas of unsatisfactory slope information.

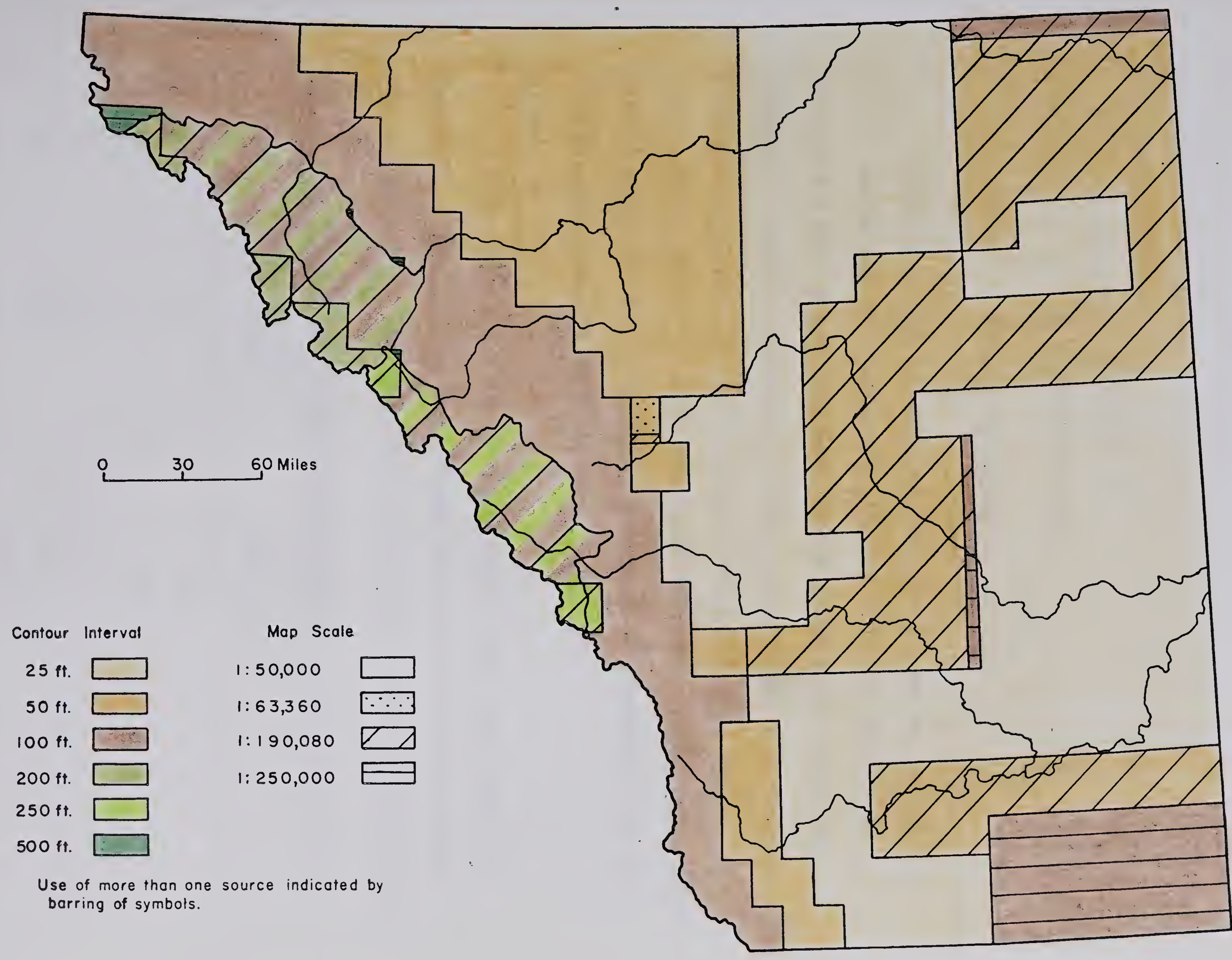

Figure 5. Sources of relief information.

CHAPTER IV

MAP CONSTRUCTION

Classification

Before areas of similar land form can be delimited, it is necessary to establish classes for the different elements used, since for each there exists an infinite number of values. Unless the map is produced for some specific purpose, such as indicating potential land use, any classification is to some degree arbitrary. Moreover, class limits must be such that the available information can be fitted into the classification.

Slope

The limits of the slope classes used are shown in Table II. Two points concerning the classification should be emphasised. Inclinations of the value of the lower limit

TABLE II: SLOPE CLASS LIMITS

Class	Lower Limit (per cent)	Upper Limit (per cent)
A	0	<5
B	5	<10
C	10	<20
D	20	<50
E	50	<100
F	100	∞

of any class are included within that class; thus, a slope of 5 per cent is included in class (B), and a slope of 10 per cent in class (C). Secondly, as discussed earlier, the classes refer to the modal average slope. At least 50 per cent of the horizontal extent of any area outlined has inclinations within the class.

Slopes are measured in percentage values, which express the change in elevation per one hundred horizontal units. These are easily converted to angular units, as a slope of "x" per cent makes an angle of $\tan^{-1} x/100$ with the horizontal. Their use here was determined partly because the class limits used in the Alberta Soil Survey Reports do not translate into convenient figures in degrees. In addition, however, the use of the per cent unit gives a greater range of integer values for purposes of subdivision. This is especially valuable in considering areas of gentle slope, where small differences in inclination are often important in distinguishing land form types.

Calef and Newcomb outline three methods of aiming at slope class intervals: (1) they may be established arbitrarily in advance; (2) an area may be divided by inspection of a topographic map, and class limits established to reveal as many differences as possible; or (3) selected terrain boundaries may be shown.[1] A combination of the first and

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[1]W.C. Calef and R. Newcomb, "An Average Slope Map of Illinois," A.A.A.G., Vol. 43, 1953, pp. 305-316.

third methods was used here. Although the classification was established prior to mapping, a brief study was first made of the type of slope values present in the map area, using 1:25,000 and 1:63,360 maps, and stereoscopic pairs of air photographs. The visual and functional significance of these values were both considered. Three factors therefore affected the choice of slope class limits. They were: the emphasis of contrasts in appearance of the land form, the functional significance of different slope values, and the limits employed in the sources used.

The range of values included in each class increases as the angle of slope increases. At lower inclinations, a small absolute increase in slope is a large relative increase, and is important both visually and functionally. There is also the practical consideration that steeper slopes have a proportionately smaller horizontal extent, and it is therefore impossible to show them in such detail.

The limits of classes (A) and (B) were determined by the use of the Soil Survey Reports as a source for those areas in which such slopes predominate. Although quantitative limits are not given in the earlier reports, and vary within 1 or 2 per cent in later reports, a 1963 survey proposed the following classes for soil mapping in Canada:

Class	Limits (per cent)
A, B, C	0 - 5
D	6 - 9
E	10 - 15 . . .

and states that these limits had already been generally

followed.[2] They approximate closely the class boundaries used on the Soil Survey of the Edmonton sheet (see Table I), and those used in this study. Because of the source used, classes (A) and (B) inevitably have some relationship to potential land use. The upper limit of class (C) is also related to this, as a slope of 11° (19.44 per cent) has been recognised as a general upper limit for regular mechanical cultivation.[3] In the prairies a limit of 15 per cent was early recognised, but slopes as low as 9 per cent may not be cultivated if other factors are unfavourable.[4] Class (C) therefore coincides with slopes which are transitional as regards mechanised agricultural land use.

The limits of these classes also serve reasonably well to portray land form differences apparent on air photographs and topographic maps. In much of the plains region, different glacial landforms are distinguished largely on the basis of form. Slopes of such landforms apparent on air photographs were estimated directly from these, or measured on those maps available with a 10 foot contour interval. A limit of 5 per cent commonly differentiated areas of ground moraine and lacustrine deposits, while only in areas of well-developed hummocky disintegration moraine or sand dunes were a large proportion of slopes over 10 per cent. The 20 per cent limit

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[2] National Soil Survey Committee of Canada, Report on the Fifth Meeting, Winnipeg, March 4 to 8,1963, p. 60.

[3] D. R. Macgregor, "Some Observations on the Geographical Significance of Slopes," Geography, Vol. 42, 1957, pp. 167-173.

[4] Pers. comm. W. E. Bowser, Alberta Soil Survey, Edmonton.

includes below it most of the modal slopes present in the plains region, with the exception of river valleys and a few areas of exceptionally steep modal slopes. The measurements made were not a statistically valid sample, as maps with a 10 foot contour interval are available only for the areas around Edmonton and Calgary. Nevertheless, they gave a general idea of the slope values present.

The remaining divisions are more arbitrary. All slopes steeper than 100 per cent are classed together; it should be pointed out that an inclination of 100 per cent equals one of 45°, and not a vertical slope. Although this class therefore includes half the range of possible slopes, they could all be described as extremely steep, and do not usually occupy large areas. Inclinations between 20 and 100 per cent are divided into two classes, 50 per cent being taken as the dividing value. From a rapid inspection of the 1:63360 map of the Lake Louise area, this appears to approximate the lower limit of very steep portions of valley walls in the mountain region, while most large areas of steeper slopes in the plains region, as measured on the maps referred to above, have inclincations less than 50 per cent.

The slope class limits used are compared in Figure 6 with values appearing in two general studies of slope inclinations. Macgregor has discussed selected inclinations, which are of special geographical significance, with reference to such factors as vegetation cover, run-off, and land

use.[5] There is a very close correspondence between some of these values and the class limits used here, and the latter are therefore of similar significance.

The slope categories suggested by Peltier are based on modal values of average slopes (calculated by the Wentworth formula) of seventy topographic maps.[6] The limits of the extreme slope classes are very close in value to those used here, but intervening class boundaries differ. Thus, while the slope classes used are suitable for depicting characteristics of the land form of southern Alberta, they may not, with the exception of the extreme classes, serve so well in portraying the appearance of the land form in other areas.

Relief

Local relief within an area one mile square is used to designate relief. The class limits used are shown

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[5]Macgregor, op.cit.

[6]L.C. Peltier, "Some Properties of the Average Topographic Slope," A.A.A.G., Vol. 44, 1954, pp. 229-230.

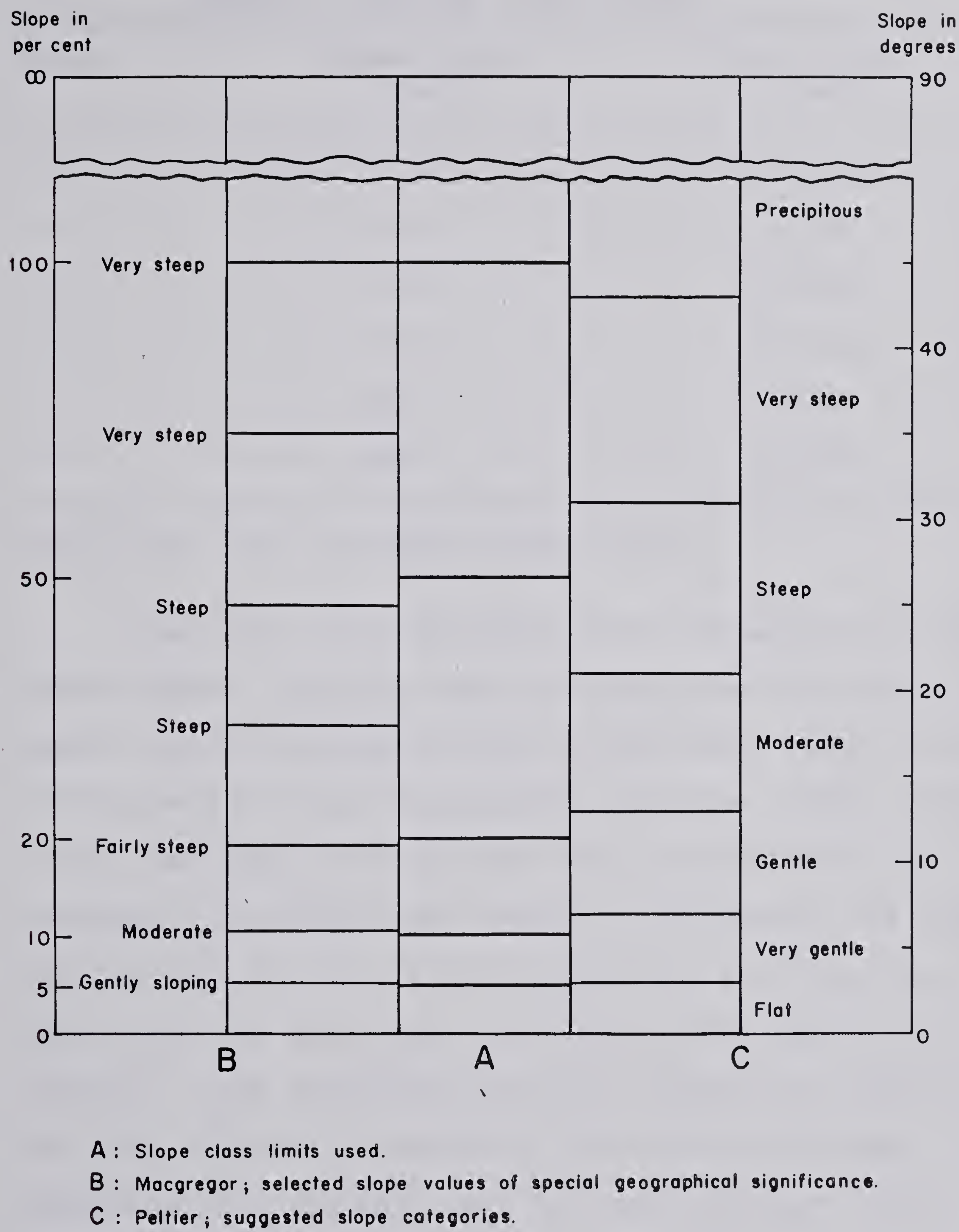

Figure 6. Comparison of slope class limits with values selected by Macgregor and Peltier.

in Table III.

TABLE III: RELIEF CLASS LIMITS

Class	Lower Limit (feet)	Upper Limit (feet)
1	0	$<$ 100
2	100	$<$ 300
3	300	$<$ 600
4	600	$<$ 1,000
5	1,000	$<$ 2,000
6	2,000	$<$ 5,000

Lower limit value included within class.

The upper limit of class (1) was determined by the lowest contour interval available throughout the plains region, where the largest areas of low local relief occur. As this was 100 feet for several districts, local relief values less than 100 feet could not be established with certainty. No areas large enough to be shown on the land form map have a local relief as great as 5,000 feet per square mile, so this value was taken as the upper limit of class (6). The remaining limits are essentially arbitrary. The class interval increases as the relief increases, in accordance with the idea that "for most purposes there is

progressively less concern with small absolute differences in relief as the relief becomes greater."[7]

Land Form Class

In most cases, a slope and a relief class are combined to give a land form class. The limits of such a class therefore consist of the conjoined limits of the slope and relief classes concerned. However, no relief value is given for areas of slope class (F). In many instances, these are too small in horizontal extent for a local relief figure comparable to that used elsewhere to be derived, while in larger areas, the relief commonly varies widely. Of the remaining thirty classes possible, nineteen occur in the map area.

Compilation

The Base Map

A map of the province of Alberta, at a scale of sixteen miles to the inch (1:1,013,760), produced in 1963 by the Department of Lands and Forests, was used as a base map. Of recent maps available at a suitable scale, this contained the greatest amount of useful information. In addition to showing lines of latitude and longitude, which mark the boundaries of 1: 50,000 topographic maps and air photograph mosaics, the map also includes the grid of the township-range survey system. This forms a network of squares approximately 0.4 by 0.4 inches on the map, which proved

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[7]E.H. Hammond, "Analysis of Properties in Land Form Geography: An Application to Broad-Scale Land Form Mapping," A.A.A.G., Vol. 54, 1964, pp. 11-19.

extremely useful for transferring information from larger scale maps, only a few of which do not show this grid. Other information contained in the base map includes hydrography, settlement and rail communication.

The grid retained on the final map is based on lines of latitude and longitude, and is equivalent to that delimiting the 1:50,000 sheets of the National Topographic System. The relationship of the numbering system of the latter to that used on the land form map is shown on the index map overlay inside the back cover. Of the other information contained in the original base map, only the major rivers and lakes are included in the final land form map. These are identified by name,and the major towns are shown,in Appendix C.

Slope

Soil Survey Reports and topographic maps were the main sources of slope information. Any description of slope conditions in the texts of the soil reports was noted on the maps, and the boundaries of the topographic classes shown were checked and generalised with the aid of mosaics and contour maps. At the same time, additional boundaries were added where necessary on the older soil maps, on which only a small number of topographic classes are distinguished. All areas shown as "hilly" were checked to see if they included any large extents of modal inclination greater than or equal to 20 per cent, as such slopes belong to a different class. Slope values for the "eroded areas" of the soil maps,

and for areas not covered by Soil Survey Reports, were derived from contour maps. Scales were constructed showing the spacing of contours at slope class limit values for the different map scales and contour intervals used. It was then possible to decide which slope class should be assigned to an area by placing the appropriate scale over the contour map. Slope values shown for areas of permanent ice are those of the ice surface. Boundaries delimiting areas in which at least 50 per cent of the inclinations belonged to the same class were sketched on the contour maps. These were necessarily very general, especially on 1:50,000 maps, where a reduction of twenty times was involved.

The information was transferred to the final map using the township - range grid as a guide. Some of the 1: 50,000 maps of the mountain area do not include this grid, and in these cases the latitude and longitude grid marking the edges of the sheets was used. Intersections of slope class boundaries with the grid lines, and the location of important points, were determined by measurement.

Most of the problems involved in delimiting areas of different slope were related to the need for generalisation. As indicated above, boundaries apparent on large-scale maps had to be greatly simplified. This was accomplished partly by omitting minor indentations, but largely by ignoring small areas of different slope. Raisz implies that areas as small as one square mile can be shown at a scale of

1: 1,000,000.[8] However, this is practicable only for isolated areas of this size(0.0625 by 0.0625 square inches at the scale used here.) Many such areas in close proximity would result in an extremely detailed map. Generally, only areas four square miles (0.25 by 0.25 square inches) or over in extent were shown on the map. For important features, such as outstanding hills or valleys, this was reduced to two square miles (0.125 by 0.125 square inches), and very occasionally, to one square mile. Linear features were shown only where their width was at least half a mile (0.03 inches).

Transitional areas of small extent, were generally problematical. This was especially apparent in association with river valleys, where areas of comparatively steep and areas of comparatively gentle slope are often separated by a narrow area of intermediate slope. In some cases, this was included in the width of a line. Elsewhere, it was included within the area of lower slope class, although its inclination was ignored in calculating the modal average slope since it occupied only a small portion of the area.

A further problem in the classification of mountain valleys was that slopes often decrease gradually toward the centre. The areas of steeper slope to either side were delimited first, and where the remaining area was too small to be further subdivided, the most prevalent slope value, as

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[8] E. Raisz, General Cartography, New York, 1948, p. 279.

indicated by the contour spacing, was assigned to the whole area. Wider valleys were subdivided so that inclinations of the designated value are prevalent in each area. The large contour interval used on maps of the mountain regions means, however, that between - contour average slope values for such areas of gentler inclination are subject in large measure to the disadvantages discussed earlier.

Portrayal of slopes associated with valleys was also a problem in the plains region. The major valleys typically have steeply sloping sides, and fairly level floors, but their total width is commonly too small for both characteristic slopes to be shown. Although in terms of horizontal extent the gentler inclinations of the valley floor predominate, the slope class of the valley walls was mapped over the whole area, since the steeper slopes form an important feature of the land form. Moreover, the slope class of the valley floor was often identical to that of the surrounding area. Sand dune areas were treated in a similar manner, as here too the steeper dune slopes are a distinguishing characteristic, although they may occupy less than 50 per cent of the area concerned.

Relief

Topographic maps were the sole source used for deriving local relief values. Tables were calculated showing the relief class corresponding to the number of contours present, for the different contour intervals used. Squares representing an area one mile by one mile at the

different scales were drawn on transparent paper, and by placing the appropriate square in different positions within an outlined area of one slope class, and counting the contours present, the relief class could be judged. The most frequently occurring value was generally assigned to the entire area. However, when a sufficiently large portion of an area had a different local relief, it was differentiated.

The main problem in mapping relief was that an exact value of local relief cannot usually be obtained from contour maps, while the estimated range of values may cross the boundary value of two relief classes. For example, the possible relief of an area having the stated number of contours, assuming a 50 foot contour interval, is shown in Table IV.

TABLE IV: POSSIBLE RELIEF FOR CONTOURS AT A 50 FOOT INTERVAL

No. of contours	Possible relief (feet)
0	0 to <50
1	>0 and <100
2	>50 and <150
.	.
.	.
.	.
.	.
6	>250 and <350

From this it can be seen that if two contours are present the area could have a relief of class (1) (0-100 feet) or of class (2) (100 - 300 feet); if six contours are present, the relief could be of class (2) or class (3) (300-600 feet).

In such cases where estimates of local relief for most areas one mile square were indeterminate, the relief class was decided by the relative proportion of other squares including a greater or lesser number of contours. For example, if, with a 50 foot contour interval, most squares contained two contours, while a few contained three, and a smaller number only one, the area was placed in relief class (2). Where spot heights are given a more exact estimate of the local relief can be made, as they are usually located near the highest or lowest points of an area.

A further problem concerns those areas, of significantly different slope, less than $\sqrt{2}$ miles (0.09 inches at map scale) in width.[9] For these cases, the local relief, within the slope class boundaries, in one mile of length was estimated. The local relief values shown for such areas are, therefore, not strictly comparable to those shown elsewhere. However, it was desirable to indicate such areas of different slope, while, at the same time, an area smaller than one square mile would not have included the full length of typical slopes in several districts.

In the mountain region, individual slopes were frequently divided by a slope class boundary. This was unavoidable, and the local relief typical of each slope class area is indicated on the map.

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[9]Since local relief was measured in an area one mile square, the maximum length that can affect its value is that of the diagonal of the square, which is $\sqrt{2}$ miles.

CHAPTER V

THEORETICAL IMPLICATIONS OF THE LAND FORM CLASSIFICATION

In the previous chapters the adequacy and reliability of the sources, and the nature of the arbitrary and subjective decisions requisite in the compilation of the land form map have been discussed. The remaining chapters are concerned with the interpretation of the information contained in the resulting map. This is first considered in abstract, then the land form of southern Alberta, as indicated by the map, is discussed.

Characteristics of the land form in any single-class area, and contrasts in land form between areas, can be derived from the map. The primary map boundaries indicate changes in modal average slope, and may also correspond with changes in local relief. Secondary boundaries outline areas possessing similar slopes to, but markedly different local relief from, the adjoining land. The value and variations in value of either element are thus shown directly.

However, the combination of a particular relief class with a slope class indicates implicitly some additional

information about the form of the land.[1] With reference to any uniform slope, considered in two dimensions, the change in elevation (relief) is a function of angle and length of slope. This relationship can be used to calculate the maximum and minimum lengths[2] possible for slopes of class limit inclinations to possess a change in elevation within the relief class limits. In considering a land surface, however, the position is more complex, as the relief of an area is not usually related to one uniform slope. The local relief value shown on the map reflects the inclinations and lengths of all slopes in an area one mile square, but for purposes of discussion the latter may be resolved into three factors: (1) the inclination of modal slopes; (2) the length of modal slopes; and (3) the nature of non-modal slopes.

Land Form in A Single-Class Area

The only definite quantitative information imparted is that explicit in the land form class limits. With regard to slope, it can be assumed that at least 50 per cent of any outlined area has inclinations within the class limits. This permits not only variation of slope angle within the class limits, but also the possibility of small areas of any

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[1]Discussion concerning such information refers only to those areas whose shortest dimension is equal to or greater than $\sqrt{2}$ miles (0.09 inches at map scale), since the local relief value shown for the remaining areas is not strictly comparable to that generally given.

[2]The term "length" applies to the horizontal equivalent of a slope unless otherwise specified.

inclination. The relief class indicates the local relief present within most included areas one mile square. Actual values may vary within the class limits, and in a few instances may lie outside the class. In addition, this value is not necessarily equal to the local relief of the total area; that is, any broad regional slope is not indicated.

Length of Modal Slopes

If local relief were measured over the same area as modal average slope, no slope within the area could have an inclination and length which would produce a change in elevation equal to or greater than the upper limit of the relief class. Thus the absolute maximum length possible for any modal slope could be derived. However, the smallest area that can be generally shown at the map scale is four square miles; the local relief of such an area would commonly be determined by the regional slope moreso than by actual slopes, and the derived value would not approximate actual maximum lengths of slope. A local relief value shown for any area on the map applies to most of the included areas one mile square, and, referring to Table V, column (3), the following conclusions can be drawn concerning the probable maximum lengths of modal slopes in areas of the various land form classes:-

1) For those instances where the values shown are greater than 7,466 feet ($\sqrt{2}$ miles), modal slopes may have

any length.[4]

2) For the remaining cases: in all included areas one mile square having a local relief within the class limits, the maximum possible length of modal slopes is that shown in Table V, column (3). The cumulative length with regard to each vertical direction is similarly curtailed. In areas of these land form classes, only a few modal slopes can have a greater length.

Number of Slopes

For areas of any land form class, the proportion of land having modal inclinations in any included area one mile square may vary from 0 to 100 per cent, since the modal slope value shown applies to the total outlined area. The local relief in a large proportion of included areas one mile square lies within the class limits. Assuming that at least one such included area has 50 per cent of its inclinations of modal value, and a local relief within the class limits,[5] the following deductions may be made concerning the number of slopes present.

1) For all land form classes the area may be undulating,

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[4] Since local relief was measured at random with regard to slope orientation, in an area one mile square, a slope may continue indefinitely if its relief does not exceed that of the relief class in a distance shorter than the length of the diagonal ($\sqrt{2}$ miles).

[5] It is doubtful if it can be proved that this occurs in all possible cases, but since the most frequently occurring values of both slope and local relief are indicated, it is highly probable.

since it is only necessary for one slope to possess the stated relief. The total outlined area, therefore, may also be undulating.

2) It is impossible for some land form classes to represent a single slope in any such included area. The limitations occur with regard to areas of steep slope and low local relief, where the maximum length of slope is limited. If the latter is such that more than one slope must be present in a distance of $\sqrt{2}$ miles, then the land form class cannot represent only one slope. Considering slopes of modal inclination, the above is true when the value shown in Table V, column (3) is less than 7,466 feet.

If the areas of non-modal slope present have less than modal inclination, the possible maximum length of a slope is increased. This effect can be allowed for by considering the limiting case where slope segments of less than modal inclination have a value of 0 per cent. For any distribution of such level areas, more than one slope (having at all points an inclination less than the upper limit of the modal class) must be present if the value shown in Table V, column (3) is less than 3,733 feet ($\sqrt{2}/2$ miles). The effect of non-modal slopes having inclinations steeper than the modal class is to decrease the possible maximum length of slope, and is therefore of no consequence here.

If more than one slope must be present in any included area one mile square, then the total outlined area cannot represent a single slope. The land form classes for which

TABLE V: MAXIMUM AND MINIMUM SLOPE LENGTHS WITH REGARD TO LAND FORM CLASS LIMITS

Land Form Class	Slope Length (feet) For slope of lower limit value Minimum ⩾	Maximum <	For slope of upper limit value Minimum >	Maximum ⩽
(1)	(2)	(3)	(4)	(5)
A1	0	∞	0	2,000
A2	0	∞	2,000	6,000
B1	0	2,000	0	1,000
B2	2,000	6,000	1,000	3,000
B3	6,000	12,000	3,000	6,000
C1	0	1,000	0	500
C2	1,000	3,000	500	1,500
C3	3,000	6,000	1,500	3,000
C4	6,000	10,000	3,000	5,000
D1	0	500	0	200
D2	500	1,500	200	600
D3	1,500	3,000	600	1,200
D4	3,000	5,000	1,200	2,000
D5	5,000	10,000	2,000	4,000
D6	10,000	25,000	4,000	10,000
E3	600	1,200	300	600
E4	1,200	2,000	600	1,000
E5	2,000	4,000	1,000	2,000
E6	4,000	10,000	2,000	5,000

Columns (3) and (4) indicate, respectively, the maximum and minimum lengths possible for slopes of modal inclination to possess a relief within the relief class concerned.

this is true are listed in Table VI.

TABLE VI: LAND FORM CLASSES FOR WHICH A SINGLE SLOPE IS THEORETICALLY IMPOSSIBLE

Slope of any inclination	Slope of modal inclination
B1	B1
	B2
C1	C1
C2	C2
	C3
D1	D1
D2	D2
D3	D3
	D4
E3	E3
E4	E4
	E5

Applies only to areas $\sqrt{2}$ miles or more in width.

(3 The possibility of having two slopes in an area one mile square varies with the angle of intersection of the slopes, and their orientation with regard to the square. The angle of intersection may vary from 0° (that is, the slopes are parallel) to nearly 180°, and the maximum length of slope necessary for only two slopes to be possible increases as the angle of intersection increases. Therefore for those land form classes for which it is impossible to have two parallel slopes in any area one mile square, it is impossible to have any arrangement of two slopes. This applies where

the value shown in Table V, column (3) is less than 3,733 feet ($\sqrt{2}/2$ miles) in considering slopes of modal inclination, and less than 1,867 feet ($\sqrt{2}/4$ miles) for slopes of any inclination. The land form classes for which it is impossible to have two slopes in any included area one mile square are shown in Table VII.

TABLE VII: LAND FORM CLASSES FOR WHICH TWO SLOPES ARE THEORETICALLY IMPOSSIBLE

Slopes of any inclination	Slopes of modal inclination
	B1
C1	C1
	C2
D1	D1
D2	D2
	D3
E3	E3
	E4

Applies only to areas $\sqrt{2}$ miles or more in width.

With reference to the total outlined area, it is therefore also impossible for these land form classes to represent only two slopes.

With one exception, the cases shown as being theoretically impossible do not occur in practice. The exception concerns the steep-sided, flat-floored valleys of the plains region, where it proves impossible because of the map scale to delimit both slope areas. Many such valleys are shown as areas, greater than $\sqrt{2}$ miles in width, of land form class (C1) or D2). The apparent contradiction

arises because, in terms of horizontal extent, the steeper slopes occupy less than 50 per cent of the total area; that is, in order to be theoretically consistent, such areas should be designated by a lower modal average slope class.

Contrasts in Land Form

Contrasts in modal slope alone or in local relief alone are indicated directly by the map. The division of slope and relief values into classes may produce artificial boundaries on the map when in reality there is a gradual change. This is especially applicable where two sequent classes are in juxtaposition. Where two non-sequent classes are adjacent, however, a pronounced change in value of the element concerned within a distance of half a mile is indicated.

Considering the land form classes which occur in the map area, it can be seen that, in general, local relief increases as modal slopes become steeper. This is to be expected, since local relief is measured for a constant area. However, further contrasts in land form can be deduced for those areas having either a slope or a relief class in common. These contrasts concern the three factors to which local relief may be related.

Areas of Identical Slope but Different Relief Class

Considering each factor in turn, and holding the other two constant, the possible variations of each in an area of higher relief compared with one of lower relief are examined

below. The examples cited are derived from Table V.

1. Inclination of Modal Slopes

The average inclination of modal slopes is greater in the area of higher local relief. The ranges of modal inclinations present may be completely distinct, or may overlap. In an area of slope class (C), for example, if modal slopes have a length slightly less than 1,000 feet: inclinations of 10 per cent would result in a relief of class (1), whereas inclinations of almost 20 per cent would produce a relief of class (2). This factor alone can account for a higher local relief only when an inclination within the modal class cannot produce the necessary change in elevation in the specified distance; that is, when the value shown in Table V, column (2) is equal to or greater than the specified length.

2. Length of Modal Slopes

The area of higher local relief has cumulatively longer modal slopes, with reference to one vertical direction. Considering again an area of slope class (C), and assuming that all modal slopes have an inclination of 5 per cent: if the slope lengths are less than 1,000 feet, the relief will be of class (1); if they are from 1,000 to less than 3,000 feet, the relief will be of class (2); and so on. Higher local relief can be produced by variation in this factor alone only when the minimum possible length of a modal slope Table V, column (4) is less than 7,466 feet for the higher relief class considered. It can be seen that this requirement

is fulfilled for all the land form classes present.

3. Nature of Non-Modal Slopes

The area of higher local relief has non-modal slopes of steeper average inclination, or greater average length, or a combination of these, all referring to the cumulative effect in one vertical direction.

Areas of Identical Relief but Different Slope Class

Similar variations in the three factors account for an increase in modal average slope with no change in relief class. The possible variations in each factor, comparing an area of steeper modal slopes with one of gentler modal slopes, and assuming the other two factors constant, are as follows. Examples are derived from Table V.

1. Inclination of Modal Slopes

The average inclination of modal slopes is nearer to the lower limit of the class in the area of steeper slopes, while the reverse is true in the area of gentler slopes. For example, for areas of relief class (2), and modal slope lengths of just under 1,500 feet, the average inclination of modal slopes in an area of class (D) must be near 20 per cent, while in an area of class (B), it is closer to 10 than to 5 per cent. This factor alone can account for a constant local relief whenever, for a specified length, inclinations of both slope classes concerned can possess the stated relief. That is, when the ranges of values in Table V, columns (3) and (4) overlap.

2. Length of Modal Slopes

Slopes of modal inclination are shorter in the area of steeper slopes. Comparing modal slope lengths in an area of class (D3) with those prevalent in an area of class (B3), for example: modal slopes in the first area are generally shorter than 3,000 feet in length, whereas such slopes in the second area may have any length, and, ignoring the effect of non-modal slopes, the cumulative length must be greater than 3,000 feet in many included areas one mile square. This factor alone can account for a constant local relief whenever inclinations within the lower slope class concerned can produce the stated relief in a distance less than 7,466 feet. It can be seen in Table V, column (4) that this condition is satisfied by all the land form classes which occur.

3. Nature of Non-Modal Slopes

In the area of steeper modal slopes, a low relief class may reflect the presence of a comparatively high proportion of non-modal slopes of less than modal inclination, and a pattern of distribution such that they affect the local relief value in many included areas one mile square. The reverse is true with regard to an area of less steep modal slopes.

It is noticeable that for all the land forms present, (as indicated by the land form classes), differences in inclination and length of modal slopes can account for the contrasts observed.

CHAPTER VI

THE LAND FORM OF SOUTHERN ALBERTA

The variation of several characteristics of land form within southern Alberta is revealed by the land form map. Additional information is referred to in the following text, especially with regard to absolute elevation, in order that features indicated by the map may be specifically described. The map does not replace studies based on genetic classifications, but is complementary to them. The two are inter-related in that the ultimate purpose of the latter is to explain differences in land form, and it is therefore initially suggested by these differences. Consequently, reference is also made to geological and geomorphological interpretations of the land form. In order to avoid tedious repetition, the land form classes are considered as being arranged in an ascending series: (A1), (A2), (B1), (B2), ... (E5), (E6). Thus (D5) is a "higher" class than (D4), but "lower" than (E3).

Southern Alberta is generally divided physiographically into three regions, mountains, foothills and plains.[1] These terms, and the land forms they describe, have been variously

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[1] J.A. Allen, Geology, Research Council of Alberta, Report No. 34, Edmonton, 1943, p. 12. See Appendix C.

defined. The term mountain has been said to:

> imply predominantly steep slopes and considerable vertical development . . . although . . . the average slope of most great mountains probably does not exceed an angle of 20 or 25° [36.4 or 46.6 per cent] from horizontal. A few exceed 35° [70 per cent] . . .[2]

With regard to relief, "the higher mountains [of the western United States] seldom exhibit relief in excess of 5,000 feet, figures of 2,000 to 4,000 feet being more nearly the rule."[3] Although "average slope" is not necessarily equal to modal average slope, and it is not specified whether "relief" is measured from crests to valleys, or in a prescribed area, it is probable that such a land form would be distinguished by slope classes (D) and (E) and relief classes (5) and (6). Other definitions add the phrases "characterized by narrow summits"[4] and "of greater altitude than a hill"[5] to this description, implying that mountains are also distinguished by having gentle slopes only at low levels, and by high absolute elevation. Neither of these characteristics are indicated on the map. The last quotation suggests that hills also may be defined in part by absolute elevation. Van Riper, however, defines hill land in terms of a local relief, from crest to valley, of 200 to 2,000 feet, and slopes

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[2]V.C. Finch, _et al._, _Elements of Geography_, New York, 1957, p. 330.

[3]_Loc. cit._

[4]J.E. Van Riper, _Man's Physical World,_ New York, 1902, p. 610.

[5]W.G. Moore, _A Dictionary of Geography_, Harmondsworth, England, 1961, p. 117.

greater than 5 per cent.[6] This would include all slope classes higher than (A), and could include all relief classes from (2) to (5) inclusive.[7] In the same classification, plains are defined as extensive areas of slope less than 5 per cent, and local relief less than 200 feet. Thus large areas of land form class (A1) and probably (A2) would be designated as plains. Finch, however, states that inclinations in plains areas are "no more than 3 or 4° [5.24 or 6.99 per cent],"[8] so some low relief areas of slope class (B) may also be considered as plains.

The boundaries of the physiographic regions of southern Alberta have, however, been defined on maps only by geologists, on the basis of structure rather than land form. These boundaries are shown in Appendix C,[9] at a reduced scale; for purposes of comparison with the land form map, they were originally drawn at the scale of this map. The land form of southern Alberta is discussed with reference to the regions so outlined, but those areas where the form of the land and its geological designation differ are noted.

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[6] Van Riper, op.cit., p. 112.

[7] For areas of relief class (1), and slope class higher than (A), only non-modal slopes could be long enough to have a relief greater than 200 feet.

[8] Finch, et al., op.cit., p. 265.

[9] The geological boundaries north of 52° N. are from an unpublished map by L.A. Bayrock, Research Council of Alberta, Edmonton; and south of this latitude, from F.K. North

The Mountain Region

The Rocky Mountain region of the map is distinct in possessing large areas of slope class (E). A striking feature in comparison of the map with the geological eastern limit of the mountains south of latitude 52° N. is that only five small areas of class (E) occur east of the Front Ranges. With the exception of these and minor indentations shown on the map, the geological limit coincides with the easternmost limit of class (E) between latitudes 52° N. and 50° 15' N., and again south of 49° 22' N. Between these latitudes there are no large areas of class (E), but the small areas present all lie to the west of the geological limit. There is again a close correspondence between the eastern limit of slope class (E) and the more generalised geological boundary between latitudes 52° N. and 53° 30' N. North of this latitude, however, several areas of slope class (E) are excluded from the mountain region as geologically defined, although on the basis of land form they would be termed "mountains". With regard to both structure and land form, it can be seen that the width of the mountain region is much greater north of 50° 30' N.

The predominant land form classes in the region are (E6) and (D5); slope and relief values are therefore

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and G.G.L. Henderson,"Summary of the Geology of the Southern Rocky Mountains of Canada," in <u>Guide Book</u> to the Fourth Annual Field Conference, Alberta Society of Petroleum Geologists, 1954, pp. 15-81 and Map No. 1. Bayrock's boundaries are more generalised, but their southward continuations correspond closely to those of North and Henderson.

similar to those given in the definitions of mountains discussed. The former class, without exception, coincides with areas of higher elevation, as do the few areas of (E5) class present. Areas of (D5) class are generally of lower elevation than adjacent (E6) areas. In many cases, major slopes are divided between the slope classes, (E) representing the upper portion, and (D) the lower portion, of the same slope. The total relief of such slopes is therefore equal to the combined relief of the two land form classes. For example, where the classes concerned are (E6) and (D5), the slope has a relief of at least 3,000 feet.

A marked trend is apparent in the pattern of slope and relief distribution, as indicated by the shape of the land form class areas, in most of the mountain region. This is approximately northwest to southeast south as far as latitude 41° 30' N. Beyond this point, the trend gradually changes, through north-north-west to south-south-east, to north-south in the area south of latitude 50° 15' N. Its parallelism to the general structural trend of the mountains presumably reflects the influence of structure and lithology on slope and local relief. In the region of the Columbia Icefields [E7: E8: F8],[10] west of Lake Louise [H11] and in the Waterton Park area [L19: L20], however, no obvious trend is present.

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[10] [ ] is used to enclose the grid location of areas or features mentioned. The approximate position with regard to the grid square may also be indicated.

In the north and centre of the map area, three major river valleys follow the general northwest to southeast trend. The northernmost of these is the Sunwapta - Athabasca valley above Jasper. The Sunwapta valley [E7] is of class (D5), while below the junction with the Athabasca, the valley possesses a larger area of gentler slopes and lower local relief, as shown by the presence of land form class (C3) for much of its length [D5: E6: F7]. The valley is also much wider below the junction, and areas of steep (E) class slope are commonly at a distance of four to five miles from the river. At one point [E6, N.W.], however, the extension of class (D5) across the river indicates that here steeper slopes approach much closer to the river. In contrast, for a short distance above this point, very gentle slopes, of class (B), are present over much of the valley.

The North Saskatchewan River rises in the same general area as the Sunwapta-Athabasca system, but flows southeastward, again parallel to the trend of the mountain region. Its valley, of land form class (D5), is much narrower than that of the Athabasca River, but in general appearance it is similar to the Sunwapta valley. The trend of the North Saskatchewan valley is continued in that of its southern tributary, the Mistaya [G9]. This valley has a wide, gently-sloping floor, of (B1) class, in its central reaches, but a few miles above the junction with the North Saskatchewan, it becomes narrower, and includes steeper slopes.

The third major valley following the northwest to southeast trend is that of the Bow River above Banff. In its upper part [H10, S.W.], the narrow area of (B1) class, increasing through (D5) to E6) to either side, suggests that the valley has a gently sloping floor and a fairly sharp transition to steep sides. At the junction with the Pipestone River [H11], the valley becomes much wider, but the area adjacent to the river is of class (D3); that is, slopes are steeper than 20 per cent, although the local relief is less than 600 feet per mile square. This indicates the presence of comparatively low but steep-sided hills: a rough topography which is probably moraine or ice-scoured bedrock. The Bow Valley maintains its width beyond this point. A narrow area alongside the river is fairly level, but between this and the bounding (E6) class to either side is a wide area of (D5) land form class, which may represent less steep lower valley walls, or a hilly area between the river and the upper valley walls.

Numerous small areas of (D5) class elongated in a northwest to southeast direction indicate that many minor rivers also follow the general trend in this part of the mountain region. However, these areas are often not continuous valleys in the sense of containing one major river. The detailed relation of drainage to one such area is sketched in Figure 7. South of the headwaters of Whiterabbit Creek there is a decrease in elevation of 600 feet, in under three-quarters of a mile, to the Ram River valley, while a

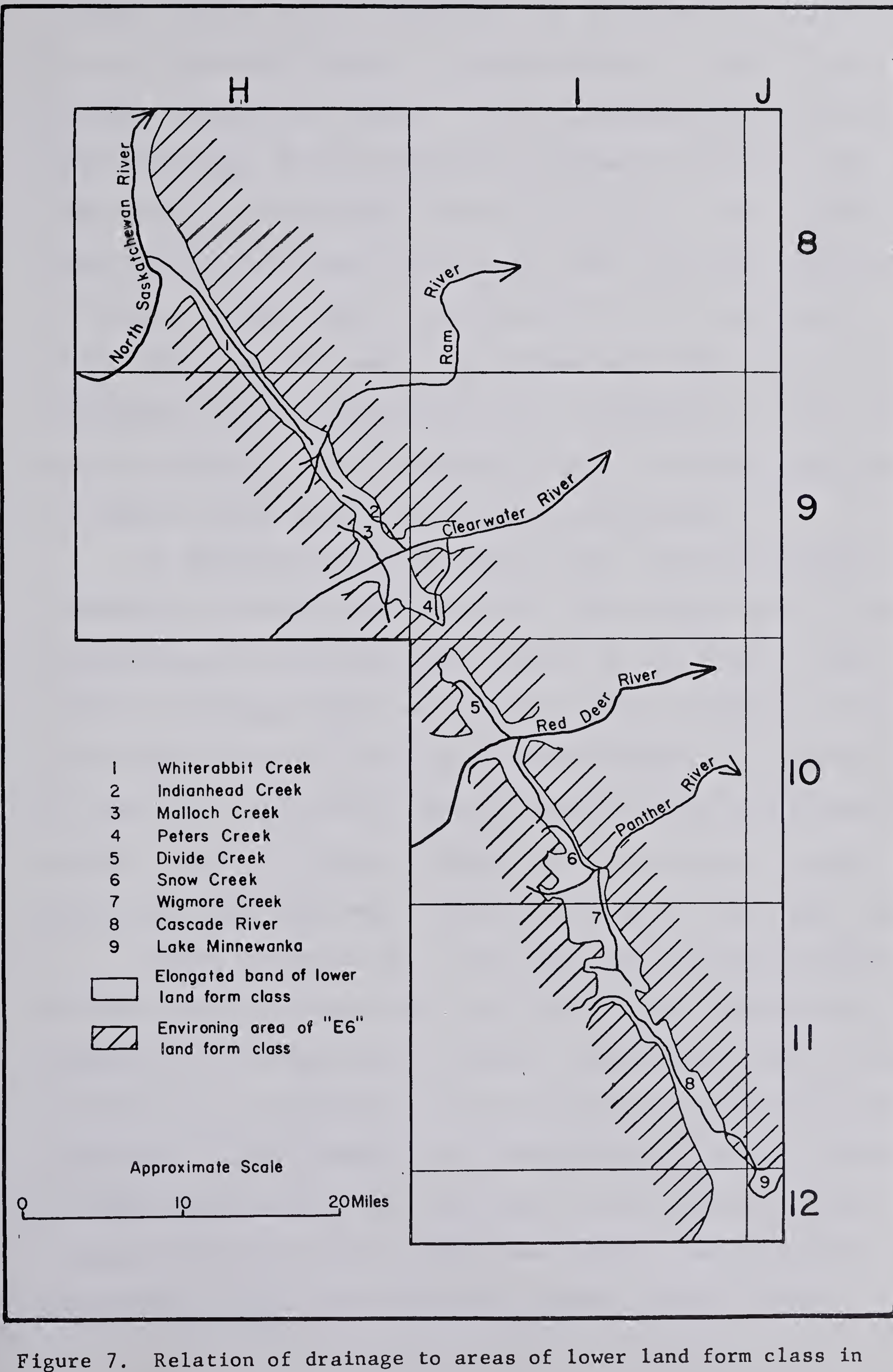

Figure 7. Relation of drainage to areas of lower land form class in grid areas [H-J:8-12].

further narrow divide separates its tributaries from those of the Clearwater River. A narrow divide of (E6) class is present between the basins of the Clearwater and the Red Deer drainage, but the watershed betwean the latter and Snow Creek is less than 100 feet in height. The Cascade River enters the area a mile and a half from the headwaters of Wigmore Creek, but at an elevation 1,000 feet lower. Thus, this area of less steep slopes and lower local relief, extending almost uninterrupted for a distance of sixty-nine miles parallel to the prevailing trend, contains portions of eleven river valleys at varying elevations.

A similar elongated area of (D5) class is present southeast of Jasper [E6: F6: F7]. The Maligne River flows northwestward in its northern part. At its head is the low divide of Maligne Pass, and south of this, Poboktan Creek and Jonas Creek both flow northward through the continuation of the (D5) area before turning west to enter the Sunwapta River. South of these, tributaries of the upper Brazeau River flow eastward and southeastward in the same (D5) band.

These examples both show that the elongated nature of the areas of lower land form class is not related to the presence of a single river valley, but suggest that it is ultimately a reflection of the influence of structure and lithology. This assumption is supported by the fact that, in the second area cited, the axis of the Poboktan Creek valley coincides with a shear zone, while the formation underlying Jonas Creek "contains random shale lenses,

which probably determine its course."[11]

Below those portions of their courses described earlier, the Athabasca, North Saskatchewan and Bow Rivers change direction, and cut across the prevailing trend. Thus the Athabasca below Jasper flows northeastwards. A further noticeable contrast with the upper valley is that only a narrow, discontinuous area of slope class (D) separates the wide, almost level valley floor, of (A1) class, from the surrounding (E6) class mountains, suggesting that there is a sharp transition between the two, compared with the more gradual transition upstream. In the lower portion of the North Saskatchewan valley, however, there is a relatively gradual decrease in both slope and local relief in cross-section. Although the distance between the bounding (E6) walls in greater than in the lower Athabasca valley, the lowest average modal slope is of class (C), in association with a relief of class (2). Only a very small area of the valley floor, if any, is level.

Both the above rivers continue in a direction transverse to the general trend for the remainder of their courses in the mountain region, whereas the Bow River resumes a course parallel to the trend after a few miles. Some interesting

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[11]R.D. Hughes, "Geology of Portions of Sunwapta and South-Esk Map Area, Jasper National Park, Alberta," in Guide Book to the Fifth Annual Field Conference, Alberta Society of Petroleum Geologists, 1955, pp. 69-116.

features of the Bow valley at this point are suggested by the pattern of the land form classes. The level area of (A1) class adjacent to the river immediately upstream continues east towards Lake Minnewanka,[12] while an area of (D5) class extends across the river, indicating that the valley is narrower, and steep slopes exist close to the river. A short distance downstream, the valley again has a level floor of (A1) class wide enough to be differentiated on the map.

The presence elsewhere of similar elongated areas of lower land form class indicates that other major rivers also bear little relationship to the prevailing trend. The Brazeau River, below that section of it mentioned earlier, turns abruptly to the northeast; its valley is at first quite narrow, of (D4) class [F7:G7], but then increases in width, while the included slopes decrease in inclination to class (C)[H9:I9]. The Red Deer river also flows to the east, cutting across the general trend [I10]. With reference to modal average slope and local relief, its valley is similar to the upper portions of the Brazeau and Clearwater valleys mentioned above, as it also is designated by (D4) land form class.

Many minor rivers also cut across the general trend. An example is the Panther River, shown in Figure 7. Its valley, however, is not differentiated as an area of

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[12]This level area probably marks the former course of the Bow River, which at one time flowed east through Lake Minnewanka. See, Guide Book to the Thirteenth Annual Field Conference, Alberta Society of Petroleum Geologists, 1963, p. 28.

lower land form class, suggesting that the cross-sectional form differs along its length, the sides being steeper, and the depth greater, where the river crosses the (E6) areas.

Several anomalous patterns of drainage with regard to slope are also indicated in Figure 7, in the cases of Indianhead Creek [H9], Peters Creek [I9] and Cascade River [I11: I12]. These all flow for a short distance in the area of lower land form class, and then, with no major change in direction, cross into the adjacent (E6) area shortly before joining a larger river, or entering Lake Minnewanka.[13] Thus in their lower portions, the valleys may be described as gorge-like, in contrast to the wider valley containing gentler slopes immediately upstream. Assuming that the general trend in the pattern of distribution of the land form classes reflects the influence of structure and lithology, the anomalous relation of these rivers to that pattern suggests that they are not well-adapted to structure, and that a genetic explanation such as local diversion, superimposition, or antecedence may exist. On the other hand, the varying cross-sectional form of each valley probably reflects the influence of lithology on slope and local relief.

The land form class most typical of the mountain

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[13]That these are not hanging valley is indicated by the continuation of the (D5) strip to the large river valley.

region is (E6), but in a few locations, areas of (E5) class occur. Such areas represent blocks or ridges of mountains having slopes steeper than 50 per cent and a local relief between 1,000 and 5,000, but generally greater than 2,000, feet per mile square. To some extent, the map indicates by the width of the (E) class areas those districts where comparatively well-defined ridges of mountains are separated by fairly wide areas of lesser slope and lower local relief. Immediately north and south of Banff, for example, three sub-parallel areas of (E6) are present [I12: J12]. These represent from east to west, the Cascade- Rundle; Norquay - Sulphur - Goat; and Sawback-Bourgeau Ranges, three major fault block ridges of the Front Ranges.[14] Again, southeast of Jasper, a series of comparatively narrow, sub-parallel areas of (E6) represents the upper slopes of several mountain ridges [E6: F7]. The largest area is the Mount Kerkeslin - Endless Chain ridge, which flanks the Athabasca-Sunwapta valley on the latter's east side.

In contrast are those districts where the mountain peaks and ridges are not separated by wide areas of lower land form class, resulting in comparatively broad areas of slope class (E), such as occur southeast of Banff [I13: J13] and in the region between the Brazeau and North Saskatchewan

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[14] North and Henderson, op.cit.; and J.L. Usher, "The Geology of the Western Front Ranges South of Bow River," in Guide Book to the Ninth Annual Field Conference, Alberta Society of Petroleum Geologists, 1959, pp. 23-36.

Rivers [G7]. These contrasts suggest the degree to which dissection has progressed in different areas within the mountain region.

Between latitudes 50° 15' N. and 49° 22' N., there is a strikingly different pattern of distribution of areas of slope class (E). A much smaller proportion of the region has slopes of this class, while many of those areas that are present have a local relief of class (5). Land form classes (E5) and (E6) occur only in a narrow area adjacent to the British Columbia border, and as isolated, narrow but long, north to south bands further east. As in other parts of the mountains, these areas represent mountain ridges, of which the most prominent in the east is the Livingstone Range [L16, L17].[15] The eastern ridges may be as much as 2,000 feet higher than elevated areas to the east and the west, but values less than 1,000 feet are more common. In comparison with areas further north, the land form in these latitudes is more like that of the foothills than of the mountain region. Elevations are generally lower, and only isolated ridges of slopes over 50 per cent occur.

Areas of modal average slope greater than 100 per cent (that is, of class (F)) occur only within the mountain region, and indicate districts where extremely steep slopes

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[15]This is the easternmost of the Front Ranges. See North and Henderson, op.cit.

predominate. Many such areas are also elongated parallel to the general trend; in addition, the shape of these areas provides some further information regarding the form of the land.

Four characteristic shapes, each representing a specific type of landform, may be recognised. Many of the (F) slope class areas are shown as straight or slightly undulating lines. In a few cases these represent the upper slopes of a sharp ridge, or arête, but more frequently they depict a steep face present on one side of a ridge only. These two possibilities cannot be differentiated from the map, but in either case it can be said that such linear areas of (F) class commonly mark the position of a ridge crest.

A second characteristic shape is an approximately circular arc, the direct distance between the end points usually varying from a half to one mile (0.03 to 0.06 inches). Several such lines may be connected, producing patterns of diverse form and complexity. Such areas are generally associated with cirques, and represent the oversteepened walls. Well-developed examples can be seen at [I10, S.W. and W.], [H9, W.] and at the junction of [D4: D5: E4: E5]. In some instances, only a short portion of the cirque wall has a modal average slope over 100 per cent, and in these cases its representation on the map is indistiguishable from a straight line. In such cases, and in other situations where areas of (F) class slope occur on a single face, the most frequently occurring direction of slope is towards the north

and east.

A further landform indicated by areas of (F) class slope is that of a horn. Such a feature typically coincides with a polygonal area, often of sharply angular circumference. Examples frequently occur at the junction of cirques [I10, W. centre], or at irregular intervals along a linear area [K14, W. centre].

The fourth type comprises those areas of (F) class larger than a mile square (0.0625 x 0.0625 square inches), whose outlines have no distinctive shape. These indicate areas in which a large proportion of the land has very steep slopes. In those examples of smaller size, one steeply sloping peak or single facet may be present, but the larger areas represent a land surface composed almost entirely of steep-sided peaks, ridges and intervening valleys. Such large areas of class (F) occur only in a few locations. They are most numerous between latitudes 52° 37'N. and 52°N. Here there are several large areas of very steep slope immediately west of the Athabasca valley [D6: E6], between the upper Athabasca and the Sunwapta valleys [E7: F7: F8], and in the vicinity of the Columbia Icefields [F8]. Approximately sixteen miles further south, the complex of steeply-sloping horned peaks and arêtes around Mounts Amery, Hodge, Monchy, and Willerval [F8: F9: G8: G9], appears as a large area of class (F). Other wide extents of steep slope are present west of Lake Louise [H11]. Especially noticeable is the narrow area projecting northeastwards from the British Columbia border where almost

all the land surface between two (D5) class areas has inclinations greater than 100 per cent. This represents the Eiffel Peak-Mount Temple ridge, which consists of extremely steep-sided peaks. The area of (F) class slopes continues along the British Columbia border, where it indicates the precipitous peaks around the heads of, and between, Horseshoe and Victoria Glaciers to the north, and around Wenkchemna Glacier and Moraine Lake to the south.

The larger part of the remaining area of the mountain region has a land form of class (D5). Modal average slopes are therefore between 10 and 20 per cent, and local relief is from 1,000 to 2,000 feet per mile square. In a majority of cases, these areas represent the central portions or the lower walls of river valleys. In four districts, however, the amount of (D5) and (D4) class area relative to the area of (E) class is noticeably large, indicating that comparatively extensive areas of gentle slopes (though still steep compared with the plains, or even the eastern foothills) and lower local relief are present.

In the northwest of the map area [A1:B1], west of the Smoky River, small patches of (E) class are separated by wide extents of (D5) and (D4) class. Although these areas are centred around rivers, they are of hilly topography. The elavation is lower than in the (E) class areas, but the height of individual hills ranges from 100 feet to over 1,000 feet. This area lies astride the geological boundary of the mountains, suggesting that here there is no pronounced change

in land form between the geological units of the foothills and the mountains.

Another large extent of (D5) class occurs west of Jasper [D6], and continues to the southeast, in the vicinity of Maligne River [E5; E6]. The area to the west represents the lower slopes of the wide Miette River valley. In the district to the southeast, however, both river valleys and intervening mountains have modal average slopes between 20 and 50 per cent, and a local relief of 1,000 to 2,000 feet. The southern part of the mountain range immediately west of Maligne River is included in the (D5) area, while its northern end has a land form of class (E6); this may reflect a change in lithology in the underlying bedrock.

Betwean latitudes 52° and 53° N., the geological boundary lies several miles to the east of the large areas of (E6) class, and extensive areas of (D5) and (D4) class are contained within the mountain region. These represent both elevated areas and intervening valleys, but the former are of less steep slope and lower local relief than the typical mountain areas, and are more similar to the western foothills.

By far the largest continuous area of (D5) class within the mountain region occurs between latitudes 50° 30'W. and 49° 22'N. The mountains (as defined geologically) in this area resemble the foothills further north, and only isolated, narrow ridges with slopes of class (E) are present. The remaining ridges, and most of the intervening valleys, have modal average slopes and local relief of the (D5) class.

It has been suggested that the striking contrast between the land form of this area compared to that of the mountains further north is related to the greater exposure of less resistant Mesozoic rocks (sandstones, shales and conglomerates) at the surface, compared to the predominantly Paleaozoic rocks (including resistant limestones, dolomites and quartzites) outcropping to both north and south; it is also observable that the faults present in this area are more comparable to those in the foothills than to those in the mountain area of the north.[16]

Areas of land form lower than (E6), (E5) and (D5) occupy only a small proportion of the mountain region, and they are all associated with icefield or valley features. The icefields present in many of the highest parts of the mountains are frequently comparatively smooth (ignoring crevasses and séracs) and of low local relief over large areas of their surface. The locations and land form classes of those differentiated on the map are listed in Table VIII. It is noticeable that no large areas of ice are present south of 51° 30' N. Modal average slopes range from 5 to 50 per cent, although without exception all large areas of slope steeper than 20 per cent are situated around the edges of the icefields, and are often indistinguishable from the upper reaches of outflowing glaciers. Only a few such glaciers are of sufficient size to be indicated on the map as separate

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[16] North and Henderson, op.cit.

land form units. These are included in Table VIII. Modal average slopes of these glaciers also range from 5 to 50 per cent, but slopes over 20 per cent are more common, and such glaciers are differentiated from typical valleys only by a lower local relief. A majority of small ice caps and glaciers, in fact, have surfaces of class (D5) or (E6) and are undifferentiated.

The remaining areas of lower land form class are associated with river valleys. All valleys may include some area of slopes of every class, due to their inherent form.[17] However, even where this is the case, a majority of such areas are too small to be shown. In addition, in the mountain region, the contour interval even on large-scale maps is too great to depict the detailed form, although where this is irregular it may be indicated by the chance intersection of a contour plane with the land surface. Consequently, in any area either too small, or too generalised on the source maps, to be subdivided, the most prevalent slope value as indicated by the contour pattern is shown, and many combinations of slope and relief class therefore occur.

Apart from those extensive tracts of (D5) and (D4) class already described as including both valleys and intervening hills, areas of these classes also are associated with river valleys, and should be included when considering the form of a valley as indicated by the map. Ignoring the question of where the valley side ends and the mountainside begins, the general form and width of the different valleys can be deduced

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[17]This is not inevitable, since a valley cross-profile is rarely a smooth curve, and slopes of some class values may be omitted.

TABLE VIII: LOCATION AND LAND FORM CLASS OF DIFFERENTIATED ICEFIELDS AND GLACIERS

Name	Location	Land form class/classes
Resthaven Icefield	B3: N.W.	C3
Coleman Glacier	B4: S.	C3
Mural Glacier	B4: S.W.	C3
Kane Glacier	D7: S.	D5
Chaba Icefild	E8: N.W.	D4, C3
Unnamed	E8: S.W.	D5, C3
Columbia Glacier	F8: N.W.	C3
Columbia Icefield	F8: N.W.	D5, C4, B2
Saskatchewan Glacier	F8: N.W.	B2
Lyell Icefield	F9: E.	D4, C4
Mons Icefield	G9: W. Centre	C4
Mons Glacier	G9: W. Centre	D5
Freshfield Icefield	G10: S.W.	C4
Conway Glacier	G10: S.W.	D5
Barbette Glacier	G10: N.E.	D4
Wapta Icefield-Peyto Glacier	G10: S.E.	C3
Vulture Glacier	H10: W. Centre	D4
Balfour Glacier	H10: S.W.	D4
Bonnet Glacier	I11: N.W.	D4

from an examination of the sequence of land form classes present in cross-section, assuming that the valley is bounded on either side by a narrow area of the highest land form class present in the district. This is usually (E6).

In many cases, the depth of the valley floor below the surrounding peaks can also be estimated by considering the combined relief of the relief classes present in cross-section. However, where the width of any one land form class area is greater than $\sqrt{2}$ miles, the total change in elevation within that area is not indicated.

If the area between the bounding class is less than a mile (0.06 inches) in width, only one land form class can be assigned to it,[18] due to cartographic limitations. Even so, contrasts between the forms of different valleys are implied. At one extreme is the case where the area between bounding (E6) walls is designated as (A1). This suggests that the valley is typically "U-shaped" in cross-section, in that very steep sides tower above a flat floor. In practice, only one such example is present in the map area, in the valley of Glacier River [G9, N.W.]. The braided channel belt of the river occupies the full width of the (A1) area, while at the eastern end, Glacier Lake extends across the valley floor. At the other extreme, many valley areas less than a mile in width are designated as (D5), between

[18] If the valley were approximately symmetrical in cross-section, the area would have to be at least one and a half miles wide in order to be subdivided.

bounding (E6) walls. This indicates that slopes less than 20 per cent are of comparatively small extent. The transverse profile may show an abrupt change from slopes of (E) class value to those of (D) class, but since class boundaries produce an artificial break in the slope profile it is probable that the valley walls decrease gradually in inclination. All other possibilities lie between these two extremes, and the contrast between the upper walls and the lower levels of the valley is greater where the latter is designated by a lower land form class.

In some instances, however, a valley is represented by only one land form class where the area between the (E6) boundaries is greater than a mile and a half in width. The land form class in all these cases is such that the area might comprise two major slopes, one either side of the river. It is also possible, however, that the central parts of such valleys include small hills. These could result from closely - spaced tributaries in well-defined valleys, or from low morainic or ice-scoured bedrock features.

Where the valley area between the bounding land form class is wider than one and a half miles, a valley of ideal symmetrical cross-section would be represented by increasingly higher land form classes from the centre outward. Such an association of land form classes is found, in fact, in a majority of those cases where the valley is of sufficient width. See, for example the Bow valley [J12] and the North Saskatchewan valley [H8]. Although without doubt the actual transverse profile of the valley is

not completely smooth, it approximates the ideal.

In a few locations, however, a situation occurs where the slope inclinations do not decrease, and may even increase, toward the valley centre. For example, the five mile wide valley area of the Miette River west of Jasper [D5] is of land form classes (D5) and (D4). The (D4) class area lies north of the river, and represents a series of ice-covered hills in the bottom of this through valley.

In three locations, all in the northern part of the mountain region, the land form class of the central area of the valley is higher than that to either side, indicating that the river is incised. The Jackpine River [B2, N.W.] has slopes steeper than 50 per cent, and over 600 feet high, ((E4) class) immediately to either side, while beyond these, the slopes decrease to between 20 and 50 per cent.

Immediately above their junction with the Athabasca River, two of its large tributaries have pronounced "benches" of lower land form class above an incised inner valley. The Snake Indian River [D4, E. Centre] flows through an area of (D2) class, while to either side, areas of class (B3) occur; thus the slopes adjacent to the river are steeper than 20 per cent, and rise a distance of over 200 feet in less than a quarter of a mile; to either side, flatter areas of less than 10 per cent slope are present. The Rocky River enters the Athabasca valley from the south at the same point. A short distance above the junction, land of class (D4) is adjacent to the river, and this continues downstream to form

the lower valley walls, between which is a level (A1) floor. Above the western (D4) wall, however, the gradient of the valley side decreases to less than 10 per cent, as indicated by the area of land from class (B2).

The association of land form classes present in any one cross-section of a valley thus gives an idea of its transverse profile at that point. Longitudinal contrasts in the form of a valley are therefore also indicated by a consideration of a series of cross-sections.

<u>Summary</u>

The typical land form of the mountain region north of latitude 50° 30'N., and again south of latitude 49°22'N., is of land form class (E6) or (E5), with intervening areas, at lower altitudes, of class (D5) or (D4). Between these latitudes, however, only a few prominent ridges are of classes (E6) or (E5), and the most extensive areas are of class (D5). Throughout the region, areas of lower land form class (that is, of modal average slope less than 20 per cent, and local relief less than 1,000 feet per mile square) are associated with icefields or valleys. A pronounced trend, varying from northwest to southeast in the north to north to south in the south, is apparent in the pattern of distribution of areas of different land form.

In many areas the geological eastern boundary of the mountains coincides with the eastern limit of the typical mountain land form, but this is not always the case. The following variations can be recognised:

(1) South as far as latitude 53° 30' N., the boundary

is not well-defined topographically, and a land form comprising small areas of (E6) class ("mountains") and large intervening areas of "low mountains to high hills" is present to either side of the geological boundary.

(2) Between latitudes 53° 30' N. and 53° N., the two boundaries correspond, and the eastern edge of the mountains is fairly well-defined topographically.

(3) Between latitudes 53° N. and 52° N., the mountain front, as indicated by the eastern limit of large areas of (E6) class, lies up to twelve miles west of the geological boundary. The eastern edge of the Bighorn Range, an outlying area of (E5) class [G6, H6, H7], however, coincides with the geological limit in the north of this area.

(4) From latitude 52° N. south to latitude 50° 15' N., with the exception of three small areas, the eastern edge of areas of class (E6) and (E5) is an almost unbroken line, which corresponds very closely to the geological boundary. The mountain front in these latitudes is therefore well-defined.

(5) Between latitudes 50° 15' N. and 49° 22' N., all the areas of land form class (E6) and (E5) lie to the west of the geological boundary, but there is no topographically defined mountain front.

(6) South of latitude 49° 22' N., there is again a close correspondence between the eastern edge of (E6) and (E5) class areas and the geological boundary, and the mountain region boundary is well-defined with regard to land form.

The Foothill Region

With regard to land form, the foothills are a transitional area between the mountains and the plains, in that classes which designate minor areas of gentler slope and lower local relief in the mountains, and minor areas of steeper slope and higher local relief in the plains, have a greater extent. The western limit of the foothills corresponds to the eastern limit of the mountains, and has been discussed in the previous section. The eastern geological boundary of the foothills cuts indiscriminately across areas of various land form classes. Generally, it lies slightly to the east of the extensive areas of slope class (D) as far south as latitude 50° 25'N. South of this point, however, large areas of class (D) slope occur to the east of the foothills.

The foothill region commonly has a land form of class (D3), (D4) or (D5). Several areas of lower land form class, especially (C2) and (C3), are included in the east, while in the west a few areas of class (E5), and occasionally (E6), are present. With the exception of areas of the last-mentioned class, therefore, the region would be termed "hill land" according to the definitions discussed earlier, but slope values in particular are generally approaching those of "mountains."

The pattern of slope and relief distribution follows a trend parallel to that of the mountains, but, in detail, to a less appreciable degree. It is plainly visible in the general outline of the large areas of slope class (D), and

is prominent locally between the Macleod and Brazeau Rivers [G4: G5: H5], and again between latitudes 51° 54' N. [K10] and 49° 30' N. [L18]. Some degree of elongation in this direction is apparent throughout the area. However, of the major rivers flowing through the foothills, the only one following the trend for even a short distance is the Oldman River, which flows north-north-west to south-south-east for a stretch of approximately twelve miles [L17: L18]. That numerous minor river valleys follow this trend in the same area, and immediately to the north, is indicated by the alignment of elongated areas of lower land form class, which here, as in the mountains, are associated with river valleys.

The areas of modal average slope greater than 50 per cent (that is, class (E)) are concentrated in the west of the foothill region, and most of them are upstanding masses. North of latitude 53° 30' N., several areas of class (E5) and (E6) are present east of the geological mountain boundary. These were mentioned earlier, and it was suggested that here the topographic boundary between foothills and mountains is not well-defined. To the south [K13], two further areas of class (E6) and (E5) occur immediately east of the geological boundary, although in this latitude the latter coincides with a well-defined mountain front. The larger of these is Moose Mountain, and slopes steeper than 50 per cent and relief greater than 2,000 feet per mile square, in addition to its name, indicate that this is an isolated mountain mass. Immediately to the southwest, Powder Face Ridge also has large

areas of slope over 50 per cent, although the local relief of between 1,000 and 2,000 feet per mile square could place the area in a hill land category. However, these areas have altitudes over 8,000 feet and over 7,000 feet respectively, compared with maximum elevations of the order of 5,600 feet only two miles to the east, so both are probably prominent features of the land form.

In three districts, isolated areas of slope class (E) are present at distances of fourteen to fifteen miles east of the geological boundary of the mountains. In the north, the Brazeau Range [I7, W. Centre] has a relief of class (5), and has been termed "an outlier of the Rocky Mountains."[19] To the south, Corkscrew Mountain [J9, N. centre] has similar modal slopes and local relief, while south of the Bow River [K14, S.W.] two small areas of class (E3) are present. A striking feature is that these three isolated areas of locally steeper slopes are in alignment, parallel to the general trend.

The areas of slope class (E) so far discussed are all elongated parallel to the trend. The two remaining areas differ in that they are extended at an angle to this. Both are associated with transverse river valleys. One represents the high and the steep south wall of the Elbow valley, where the river cuts across the north end of Forgetmenot Ridge

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[19] J.A. Allen and R.L. Rutherford, Saunders Creek and Nordegg Coal Basins, Alberta, Research Council of Alberta, Report No. 6, Edmonton, 1922, p. 27.

[K13, S. Centre]. An area to the north depicts an extremely steep-sided, narrow stretch of the Brazeau valley [G5: H5], where the river is incised to a depth of over 600 feet.

The slope values most typical of the foothills are those of class (D), while in combination with these a relief of class (4) has the greatest extent. North of latitude 49° 45' N., slopes of class (D) occupy an extremely large proportion of the region. South of this, no such extensive areas of class (D) are present east of the mountains.

The breadth of the majority of areas of class (D) suggests that valleys and ridges alike have modal average slopes of 20 to 50 per cent. That is, the former in most cases include no large areas of gentler slope. Nevertheless, those districts of lower land form class included within the (D) area are invariably associated with river valleys. In this respect, the foothills are similar to the mountains.

A local relief between 600 and 1,000 feet per mile square is typical of a large part of the foothills. North of latitude 53° 15' N., however, large areas are of relief class (5), while in many latitudes, the relief is of class (5) immediately adjacent to the mountains, indicating that slopes are steeper or longer here. The change is probably gradual, as the increase in relief is a widely-occurring trend. However, several areas of (D5) class occur further east, at, for example, [I8: J8], [J9], and [K13]. These areas are all elongated parallel to the prevailing trend,

and, except for the last example, are completely isolated from the (D5) areas adjacent to the mountains. They suggest the local occurrence of steeper and longer slopes, and in fact represent more prominent ridges within the foothills. An exceptionally sinuous band of (D5) land form class [I8, N. centre] also at first follows the general trend, but then continues at rightangles to it, before turning southeast, again parallel to the trend. The last-mentioned section represents a locally prominent ridge such as those described above. The western section of this area of greater local relief, however, marks the incised valley of the Ram River. At the southwestern (upstream) end of this portion of the Ram valley, two narrow areas of (A1) class indicate the presence of flat, bench-like features to either side of the incised river.

Generally, however, local relief decreases eastward, from class (5) adjacent to the mountains, through the most typical class (4), to class (3) in several locations in the east. This suggests a general decrease in the inclination of prevalent slopes (both within and outside the modal class), possibly combined with a diminishing length of modal slopes, from west to east. The trend of decreasing land form class is continued eastward with the appearance of areas of class (C3) and (C2).

In that part of the foothill region south of latitude 49° 45' N., the association of land form classes is noticeably different. Only a small part of the area has slopes steeper

than 20 per cent, and in several districts a land form of class (A1), (A2), or (B1) (that is, a "plains" land form) is present not in association with river valleys. In contrast, in these districts, areas of higher land form class are associated with the river valleys, indicating that the valleys are incised in an area of predominantly gentle slopes. However, the land form classes most typical of the area as a whole are (C2) and (C3), so the region may still be described as "hilly", especially in the west and south. The hills, however, have gentler slopes and a lower local relief than those characteristic of the foothill region further north. Only a few isolated areas have steeper slopes and higher local relief, and these become more numerous toward the north.

Between latitudes 50° 25' N. and 49° 40' N. quite extensive areas of slopes steeper than 20 per cent, and between 10 and 20 per cent, are present immediately east of the geological foothill region. These areas have a local relief which may vary from 300 to 2,000 feet, and 100 to 600 feet respectively, but the larger part has a relief between 600 and 1,000 feet per mile square. The land form classes present are therefore more typical of the foothills than of the plains to the east. This area represents the Porcupine Hills, which although structurally part of the plains[20] are anomalous as far as slope and local relief are concerned.

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[20]The Porcupine Hills (appear to) coincide with the axis of the Alberta Syncline, which underlies the plains. *See* North and Henderson, *op.cit.*

<u>Summary</u>

The typical land form of the foothill region is of class (D4), although the area north of latitude 53° 30' N., areas adjacent to the mountains, and prominent ridges elsewhere commonly have a relief of class (5). However, a land form region defined on this basis would exclude much of the area south of latitude 49° 45' N., and would include a major portion of the Porcupine Hills. Elsewhere, the eastern geological boundary of the foothills coincides with a change in land form only to the degree that all extensive areas of slope class (D) are confined to the west of it.

The foothills are similar to the mountains in that local areas of lower land form class are associated with river valleys; here too the area south of 49° 45' N. is an exception. A further similarity is that an approximately parallel trend is present in the pattern of distribution of areas of different land form.

The foothill region appears as an area of land form intermediate between those of the plains to the east and the mountains to the west, and to some extent the nature of this transition is indicated. Five major variations can be recognised.

1) North of latitude 53° 30' N., the eastern geological boundary coincides with a fairly narrow transition zone between low hills of (B2) class, and a typical foothills land form of (D4) and (D5) class. There are, however, several outlying areas of slope class (D), while further east more extensive

hilly areas occur. In the west, there is no well-defined topographic boundary between the foothills and the mountains.

2) Between latitudes 53° 30' N. and 50° 25' N., the geological boundaries of the three regions coincide most closely with changes in land form. However, although no large areas of class (D) are present east of the foothills, in many areas there is a transition zone (of classes (C3) and (C2)) up to sixteen miles in width between the typical foothill land form and those characteristic of the plains. In the west, with the exception of the area from 53° N. to 52° N., the mountain front is well-defined, and corresponds to the geological boundary.

3) From latitude 50° 25' N. south to latitude 49° 40' N., there is a sharp transition from the flat plains between Nanton and Fort Macleod to the steeper slopes of the Porcupine Hills. West of here, however, there is a gradual increase in local relief, and possibly in average slope inclinations within class (D), and the eastern edge of the mountains is marked only by a few isolated steeper and higher ridges.

4) Between latitudes 49° 40' N. and 49° 22' N., only a very narrow area of typical foothills land form is present between level plains and low hills to the east, and the mountains to the west. There is, however, no well-defined mountain front.

5) South of latitude 49° 22' N., no typical foothills land form is present, and there is a sharp transition from

an area of low hills and plains to the mountains. Only a few isolated areas of steep slope and high relief occur east of the mountain front.

The Plains Region

By far the greater part of southern Alberta is designated as the plains region. This is distinct in possessing large areas of comparatively gentle slope and low local relief. With the exception of the area south of latitude 49° 40' N., however, such a typical "plains" land form does not extend as far west as the geological boundary between the plains and the foothills. A transitional zone of "hills" intervenes, and its approximate eastern boundary is indicated in Appendix C. In the far north, the transitional zone has a width greater than one hundred miles from east to west, and includes several areas where the local relief is over 600 feet per mile square. The width decreases to approximately sixteen miles south of latitude 53° 15' N., and remains of this order as far south as 49° 40' N. The southern part of the zone comprises the Porcupine Hills, while in the intervening section land forms of classes (B2), (C2) and (C3) predominate; all of these would be classed as "hill land". It is noticeable (see Appendix C) that north of latitude 52° N., the eastern edge of the transitional zone approximates the eastern limit of the foothills as delineated by Rutherford in 1941.[21] The higher relief and steeper slopes present in

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[21] R.L. Rutherford, "Some Aspects of Glaciation in Central and South Western Alberta," Transactions, Royal Society of Canada, Vol. 35, Sect. 4, 1941, pp. 115-124.

this area probably reflect the influence of the underlying bedrock.

East of the transitional zone, with the exception of some river valleys, only a very few districts in the plains region have a local relief greater than 300 feet per mile square. Such a relief is associated with areas of slope class (C) or (D) and, in two instances, (B), and the districts concerned would be classed as "hills." Most of these areas are associated with bedrock at or very close to the surface. This is true of the Milk River Ridge [O19: P20] and the Cypress Hills [T18] scarps, of other areas of high local relief in their vicinity, of parts of the Neutral Hills [S8] and the Hand Hills [P10: P11], and of a small area to the west of the Wintering Hills [O12: W.]. North and west of Sylvan Lake [J4: J5; J6; K6; L7] the local relief is locally greater than 300 feet per mile square in several districts; this area lies in the west of the plains region, and it is probable that the districts are outliers of the transitional zone described earlier. In only two areas, one around Buffalo Hill [N14, E. Centre] and the other east of the Wintering Hills [P11, S.W.] does such high local relief correspond with areas of thicker surficial deposits.

With the exception of the areas mentioned, and a few locations where slopes are locally of class (D), the plains region possesses modal average slopes of less than 20 per cent, and a local relief of less than 300 feet per mile square. The three slope classes and the two relief classes

comprised by these limits are present in all possible combinations, and six classes therefore describe the land forms typical of the plains. Contrasts between areas having the same modal average slope but a different local relief are more important than elsewhere, since absolute differences in these elements are small and even extensive areas of comparatively steep slope may have a low local relief. A brief review of the points discussed more thoroughly in (pp. 59 to 61), with reference to slope classes (A), (B), and (C) in combination with relief classes (1) and (2), is therefore in order.

Within an area defined by its modal average slope, a change in local relief indicates qualitatively contrasts in the nature of slopes present. In the area of lower local relief (that is, of class (1), compared to class (2)), slopes may have gentler inclinations, though still within the modal class. However, this factor alone can be responsible only in areas of slope class (A). With regard to classes (D) and (C) therefore, low local relief must also reflect contrasts in the length of modal slopes or in the nature of non-modal slopes. Modal slopes may be shorter where relief is of class (1); for example, most slopes of 5 per cent must be shorter than 2,000 feet, whereas in an area of relief class (2) they could be almost 6,000 feet long. Finally, a greater extent of slopes less than the modal value may be present in the area of

lower local relief. A study of large-scale contour maps and air photo. mosaics of relevant areas indicates that all these factors are operative.

Only in areas of slope class (A) is it possible for a single slope of modal inclination to be present. Macgregor states that it is "almost impossible to estimate whether ground is flat or sloping at 1° or 2° [1.75 or 3.49 per cent]".[22] the latter value would produce a local relief of over 100 feet in just over half a mile, and it is therefore possible for areas of both (A1) and (A2) class to appear level in the field. Such areas could also be gently undulating, or have a gentle slope in only one direction.

Slope class (B) corresponds in large part to the "gently rolling" areas of the Soil Survey Reports. Areas of class (B1) must be undulating, since modal slopes are commonly shorter than 2,000 feet in length. They may still warrant the description "gently undulating" if slopes are near the lower limit of the class, and a large proportion of slopes less than modal value occurs. In areas of (B2) class, modal slopes may be almost 6,000 feet in length, while slopes including many stretches of less than modal inclination may have any length. Such areas may represent a "plains" land form if both slope and local relief values lie near the lower limits of the class, but, in general, they correspond to a

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[22] D.R. Macgregor, "Some Observations on the Geographical Significance of Slopes," Geography, Vol. 42, 1957, pp. 167-173.

land form of "low hills."

Slope class (C) includes both the "rolling" and some of the "hilly" areas of the Soil Survey Reports. The prevalent slopes, of 10 to 20 per cent, are much steeper than those permitted in most definitions of plains. However, in areas of (C1) class, the length of such slopes is generally less than 1,000 feet, and the relief less than 100 feet. Such districts therefore possess a very rough topography, but of lower local relief than "hill land," over much of their area. In areas of class (C2), modal slopes may have a length up to 3,000 feet, and the land form may range from extremely rough to one of "low hills."

As the pattern of distribution of land form classes in the plains region is much less regular than that apparent elsewhere, it proves impossible to discuss without frequent reference to local topographic names. Moreover, many extensive features are referred to only by widely accepted glacial geological terms, and many of these are also used of necessity in the following discussion.[23]

The most distinctive feature of the plains region is the presence of large areas of slope class (A). Such areas correspond to a "plains" land form as defined by Van Riper.[24] The largest continuous expanse extends from the

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[23]Such terms used in the text are explained in Appendix D. Information concerning surface material was derived from the Alberta Soil Survey Reports, and from those studies in glacial geology listed in the Bibliography.

[24]J.E. Van Riper, Man's Physical World, New York, 1962, p.124.

northern border between longitudes 111° 45' S. and 112° 45' W. south to latitude 51° 15' N. This level or gently undulating area, known as the Torlea Flats, is therefore almost 200 miles in length, and is a pronounced feature of the land form of east-central Alberta. Much of the area south of the Bow River and North of the Milk River Ridge is also of (A1) class, though this area is interrupted between longitudes 112° 30' W. and 113° W., where steeper slopes prevail around Lake Macgregor. Immediately east of here, however, the (A1) area extends north of the Bow River [O14: P14]. In the west of the plains, this (A1) area continues far to the north, passing east of Calgary and southwest of Red Deer. A fourth large area of (A1) class is centred around Edmonton [M2: N2], and continues westward to longitude 116° W., though not in an unbroken expanse. In addition, numerous smaller districts throughout the plains region have a land form of class (A1) or (A2).

Many of these areas correspond with lacustrine deposits. However, considering the total area of slope class (A), the larger part of it is underlain by till. In those areas mapped in detail by the Research Council of Alberta, such (A) class till areas are referred to as "ground moraine" or "flat till plain"; this is the case in the Torlea Flats area.[25] Much of the (A1) area northeast of Calgary is underlain by till, and has been described as "a large area

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[25]See the following Research Council of Alberta, Preliminary Reports, Geology: C.P. Gravenor and L.A. Bayrock, Glacial Geology, Coronation District, Alberta, No. 55-1, Edmonton, 1955; C.P. Gravenor, Glacial Geology, Castor District,

of ground moraine."[26] Land forms of class (A) are also associated with other surface materials. In the Torlea Flats west and north of Sullivan Lake [P8: Q8], for example, the till cover is very thin, and the topography here reflects the nature of the underlying Cretaceous bedrock,[27] while in some locations, the surface material is of sand or gravel.

Despite the presence of extensive areas of comparatively level land, a large part of the plains region has average modal slopes over 5 per cent. The distribution of areas of higher land form class has no distinct pattern or trend. Very generally, such areas are prevalent along both the southern and eastern margins of the plains region, while north of latitude 50° N., a further belt of steeper slopes extends northward betwenn the Torlea Flats in the east and the (A1) area already described in the west. This belt varies in width, and north of latitude 52° 40' N., is interrupted by the area of (A1) class around Edmonton. A narrow area of steeper slopes continues as far north as latitude 53° 45' N. to the east, while to the west, a broad but discontinuous area of slopes steeper than 5 per cent is present.

Considered in detail, however, all of these districts include small areas of slope class (A), while some areas of

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Alberta, No. 56-2, Edmonton, 1956; C.P. Gravenor and R.B. Ellwood, Glacial Geology, Sedgewick District, Alberta, No. 57-1, Edmonton, 1957.

[26]F.A. Wyatt and J.D. Newton, Soil Survey of Rosebud and Banff Sheets, Alberta Soil Survey, Report No. 12, Edmonton, 1943, p. 13.

[27]Gravenor, Glacial Geology, Castor District, op.cit., p. 8.

(B1) class may also appear gently undulating. Areas of class (B2), (C1) or (C2) are, however, of significantly different land form. It is such areas that are often distinguished locally as "hills", reflecting their prominence in the landscape. The three classes also commonly represent areas of hummocky disintegration moraine, or more locally, kame moraine or sand dunes, all presenting a confused pattern of knolls and ridges.

North of latitude 50° N., the western edge of the area of higher land form class along the eastern margin corresponds to the western edge of the Viking Moraine as mapped by Rutherford.[28] This area is almost eighty miles wide in the south, but is narrower between latitudes 57° 15' N. and 52° 30' N. From this point, the western edge trends north-northwest, until again steeper slopes prevail over an area eighty miles wide In the northeast, however, a comparatively wide and continuous strip of (A1) land form class trends northwest to southeast across the area [S1 to T3]. According to both Rutherford and Bayrock[29] the area north and east of this represents part of the Altamont (Coteau) Moraine, while the area to the west is a continuation of the Viking Moraine. Bretz, however, regards the area to

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[28]Two articles are referred to fequently in this section. The sources are given in full here, and in subsequent references the author is mentioned by name in the text. See R.L. Rutherford, "Some Aspects of Glaciation in Central and South Western Alberta," Transactions, Royal Society of Canada, Vol. 35, Sect. 4, 1941, pp. 115-124; and J.H. Bretz, "Keewatin End Moraines in Alberta," Bulletin, Geological Society of America, Vol. 54, 1943, pp. 31-52.

[29]L.A. Bayrock, Glacial Geology of an Area in East-Central Alberta, Research Council of Alberta, Preliminary Report, Geology, No. 55-2, Edmonton, 1955.

the west as representing the Altamont Moraine, and maps no morainal areas whatever in the north and east. Despite this, the large areas of land form class (C2) in the latter district indicate that numerous low hills, in fact hummocky disintegration moraine, are characteristic of the land form here.

Within this eastern area of generally higher land form class, many features designated as "hills" are differentiated on the map as areas of locally steeper slope or greater relief. In the northwest, the Snipe Hills [Q1, centre W.] correspond with an area of (C2) class; a spur of these, at an elevation of 2,400 feet, "is 300 feet above the area immediately south of it".[30] Akasu Hill [Q3, N.W.], at a similar elevation, projects as a spur of (B2) class into the (A1) area to the north, while it possesses a greater relief than areas of similar slope to the south. A small area of (C2) class to the south represents another isolated hill, Flagstaff Hill [Q6, S]. In the east of the Viking Moraine, the more extensive Blackfoot Hills are distinguished by a land form of class (C2) [T4], compared with slopes of less than 10 per cent and a local relief of under 100 feet in the surrounding district. These hills are composed entirely of till. Many of the local prominences further south, however, are a result of

[30] F.A. Wyatt and J.D. Newton, Soil Survey of Wainwright and Vermilion Sheets, Alberta Soil Survey, Report No. 13, Edmonton, 1944, p. 13

bedrock highs, with only a thin or patchy covering of till. The most conspicuous of these, as indicated by the land form map, are the Neutral Hills [S8, N.], where an extensive area has a local relief of over 300 feet per mile square, and slopes of 10 to 20 per cent. The local relief decreases to less than 300 feet per mile square in the southeast of these hills. The Inner Rainy Hills [R13: R14] and the Outer Rainy Hills [R15, N. centre], differentiated as areas of (C2) class, are also bedrock cored. At the same latitude, immediately west of the South Saskatchewan River, are the Middle Sand Hills [T14], of (C1) land form class. These are composed of sand and gravel, and would appear to be an area of kame moraine or sand dunes. The average modal slope of 10 to 20 per cent, combined with a local relief of under 100 feet per mile square, suggests that the hills are comparatively low, and the topography probably very rough.

Many other areas of similar land form class appear in this eastern part of the plains region. Most are underlain by till, but in some cases sand or gravel lies at the surface. All represent areas of rough topography, either hummocky disintegration moraine, or kame moraine or sand dunes. However, although the whole area is often termed an end moraine, the land form map indicates the location of numerous areas of gentler slope included in the rougher topography usually associated with this term.

North of 50° N., a further area of generally higher land form class is present to the west. No one name has been

applied to the whole area. A less extensive area than in the Viking Moraine has slopes over 10 per cent, while the boundaries are not so well-defined. In the north, areas of steeper slope associated with this band are present both east and west of the (A1) area around Edmonton.

Various names are applied to the area east of Edmonton. That part of it north of 53° N. is termed the Cooking Lake Moraine by the Soil Survey,[31] while its continuation to the south is referred to as the Beaverhills Moraine. The same area, however, forms the northern part of the Buffalo Lake Moraine of Bretz. Much of this morainal area has modal average slopes of less than 10 per cent, though in the east slopes between 10 and 20 per cent are more common. The relief is generally less than 100 feet per mile square, suggesting that the topography is quite choppy where steeper slopes prevail. It is noticeable that along the northern and eastern edge there is a narrow band where the relief is over 100 feet per mile square. This suggests that the change in modal average slope is accompanied by a change in elevation.

The areas of steeper slopes to the west of Edmonton, known in part as the Duffield Moraine, are much less continuous than those so far described. Perhaps because of this, the extent of the Duffield Moraine as mentioned in the literature varies within wide limits. Only one extensive

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[31]The Soil Survey Reports concerned in different areas are indicated in Figure 3.

district has modal average slopes over 10 per cent [L2: L3: M2]; that part within [M2] is "the beginning of a large moraine to the west",[32] presumably the Duffield Moraine. The area of class (C) slopes lies athwart the eastern margin of the Moraine as outlined by Bretz, but to the east of Moraine Number 4 of Rutherford. In both these sources, the Moraine extends westward to longitude 115° W. Sources of slope information for this area are, however, extremely unreliable. Those areas mapped as slope class (C) correspond to the "heavily rolling and hilly" areas of the St. Ann Soil Report. This is one of the early reports, published in 1930, before any standardisation whatever of topography classes was attained. In addition, the 1:50,000 topographic maps of the area have only a 50 foot contour interval; much of the area shown as class (C1) would appear on this evidence alone to have slopes of less than 5 per cent. The boundaries drawn are therefore very approximate, and represent a compromise between those apparent on the Soil Report map, topographic maps, and air photograph mosaics.

The southward extent of the Duffield Moraine as mentioned in the literature also varies. The Moraine as shown by Bretz disappears at latitude 53° N., but it can be seen on the map that areas of steeper slope are present south of here. According to the Soil Survey, the Duffield Moraine continues as an element of the land form much further south [M7, W.], where it is represented by an area of land form

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[32]W.E. Bowser, et al., Soil Survey of the Edmonton Sheet, Alberta Soil Survey, Report No. 21, Edmonton, 1962, p. 11.

class (B2). It is not mentioned, however, in the Rocky Mountain House Soil Report, which covers the area immediately to the west [L7], although there are here extensive areas of (C) class slopes formed on till. Rutherford shows his Number 4 Moraine as extending westward from 114° W. between the Red Deer River and latitude 53° N. [L5; L6: L7: L8], and this would include many of the areas of higher land form class almost as far west as the North Saskatchewan River within the Moraine.

South of the Battle River [M6], the area of generally higher land form class to the west is continuous with that to the east, which forms the Beaverhills Moraine. The northern part of this has already been described. The extent of its southern part as mapped by different authors varies. As mentioned in the Soil Survey Reports, the Beaverhills Moraine is approximately coincident with the general area of higher land form class as far south as 51° 45' N. Beyond this, the name is no longer used. Rutherford's Number 3 Moraine also extends south to 51° 45' N., but is of much smaller width than the area of steeper slopes shown on the land form map. At the point where the latter is very narrow [N4 : N5], Rutherford does not indicate the presence of any moraine; south of here, he includes only those areas of slope class (C) around Buffalo Lake [N6: N7: O6] and a small area southwest of the Red Deer River [O8: N9, N.] within the Moraine. The eastern margin of the Buffalo Lake Moraine of Bretz, on the other hand, is approximately coincident with

that of the area of higher land form class as far south as 50° 50' N. [014]. His western margin, however, although further west than that of Rutherford in the north, coincides with it southwest of the Red Deer River. South of latitude 57° 45' W., it swings east, and then south, in such a way that between latitudes 52° N. and 50° 50' N., only the narrow area of slope class (C) along the eastern edge of the central area of higher land form class is included in the Buffalo Lake Moraine.

The end moraines as mapped by Rutherford and Bretz therefore include many of the areas of roughest topography in this central region. Nonetheless, they exclude, in the west, a wide area of modal average slope greater than 5 per cent, several areas of slope class (C), and one of slope class (D). Immediately north and south of the Red Deer River, however, these areas are included in the Beaverhills Moraine of the Soil Survey Reports. The extensive area of (C2) class, and the included (D2) area, in the southeast of this district, has land forms composed of till, and presumably consists of rough hummocky disintegration moraine. The four isolated areas of (C2) class to the west [M7, E.; M8, centre], however, correspond to areas of thin till cover, and in fact represent bedrock-cored hills. To the south, Antler Hill [M8, S.W.] is also bedrock-cored, but is of (B2) class; this feature is differentiated by a greater local relief from areas of similar slope to either side. To the southeast, three other areas of slope class (C) also lie to the west of the Buffalo Lake Moraine

as outlined by Bretz, and portions of these correspond with areas where bedrock is very close to the surface. The northernmost district symbolises the Hand Hills [P10: P11], which have a local relief greater than 300 feet per mile square. An area of (C) class slopes, but of lower local relief, and underlain by till, extends from here southeast to the Buffalo Lake Moraine. A further extensive area of slopes between 10 and 20 per cent occurs south of the Red Deer River [O12: P12], the relief is generally between 100 and 300 feet per mile square, but in the east it increases to over 300 feet. This area is coincident with the Wintering Hills, which also have a bedrock-core. An area of rough (C1) class topography southeast of these is termed the Wintering Hills Moraine in the Soil Survey Reports, but in the east it coincides with the southernmost part of the Buffalo Lake Moraine of Bretz. An area of (C3) land form class a short distance to the west of the Wintering Hills, and continuing the same trend, also possesses only a thin till cover; although not named locally, it is probably quite prominent in the landscape.

No other district within the central area of higher land form class west of the Buffalo Lake Moraine, and north of the Bow River, has average modal slopes greater than 10 per cent, while many areas have slopes of less than 5 per cent, and a local relief of under 100 feet. The latter are most extensive in the areas around Drumheller, where the surface material is lacustrine in nature. However, the two

are not co-extensive, and lacustrine deposits are also present in areas of higher land form class, suggesting that they here form a thin cover over other material. Such is the case in the area of (A2) class south of the Rosebud River [N11 : O11], where they overlie hummocky disintegration moraine.[33] Much of the area, however, is underlain by till, and is probably transitional in land form between hummocky and ground moraine; it might be classed as intermediate moraine. Bedrock is again close to the surface in the Knee Hills area [M9: M10: N9], but they are not differentiated with regard to slope and local relief.

The central area of higher land form class continues south of the Bow River, and here includes two areas of slopes greater than 10 per cent. In the west this represents the Buffalo Hill Moraine [N14]; Buffalo Hill itself is distinguished by its greater local relief, of over 300 feet per mile square. An area of (B2) land form class present to the north, west and south presumably represents a gradual decrease in modal average slope away from the central area. To the east of Lake Macgregor [O14], an area of similar rough topography has been termed the Lake Macgregor Moraine.[34]

As mentioned, Bretz terminates the Buffalo Lake Moraine

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[33] A.J. Broscoe and R.H. Barton, "Geomorphology of the Drumheller-Morrin Area, South-Central Alberta," in Guide Book to the Ninth Annual Field Conference, Alberta Society of Petroleum Geologists, 1959, pp. 20-22.

[34] The names used in this paragraph are those appearing in F.A. Wyatt and J.D. Newton, Soil Survey of Blackfoot and Calgary Sheets, Alberta Soil Survey, Report No.11, Edmonton, 1960, pp. 20 and 28.

at 50° 50' N., and although he indicates several morainal areas south of this latitude, none coincide with those described above. Horberg, however, has designated an area of (B1) class immediately north of the Oldman River [P16: P17] a part of the Buffalo Lake Moraine.[35]

The regions so far described include the chief concentrations of areas of higher land form class north of those along the southern border. However, several other areas of locally steeper slopes are present in these latitudes. Many are located in the northwest of the plains, immediately east of the transitional zone already described. North of 52° 10' N., and west of 114° 30' W., extensive areas of both (A) and (B) slope class are present, and, especially between latitudes 52° 50' N. and 52° 10' N., several areas have slopes of class (C). There is, however, no easily ascertained pattern to their distribution. Between latitudes 52° N. and 50° 30' N., an area of steeper slopes, largely of class (B2) occurs east of the transitional zone, and probably represents an area of low hills.

Other isolated areas of steeper slope are present further east; those of sufficient prominence to have been named are all located in the south. Southeast of Calgary [M13: M14: N13: N14], the area of (B2) class mentioned above projects eastward and forms a wedge of slightly steeper slopes

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[35]L. Horberg, "Pleistocene Drift Sheets in the Lethbridge Region, Alberta," Journal of Geology, Vol. 60, 1952, pp. 303-330.

and greater local relief known as Gladys Ridge. South of here, several small areas of slope class (B) are present, and it is probable that many reflect local highs in the underlying bedrock. Mokowan Butte [N19], formed on bedrock, has modal average slopes over 20 per cent, and a local relief of class (2). Continuing south and north, a band of the same local relief, though with slopes less than 5 per cent, coincides with an area where there is only a thin till cover over bedrock. This area includes Wild Turnip Hill [N18], which has slightly steeper slopes. Following the same trend to the north is the elevated area of Blackspring Ridge [O16]. Most of this has slopes of class (B), but on the southwestern edge they increase to over 10 per cent. The local relief is also of higher class on the western edge.

The isolated areas of higher land form class in the southeast, however, are more often a result of local glacial deposition. The most prominent of these is the Little Rolling Hills, immediately east of Lake Newell [Q15]. They have a land form of (C2) class, and are formed of till. Other areas of locally steeper slopes formed on till occur southeast of Lethbridge [Q18:P18: P19], where two strips of land have average modal slopes of 5 to 10 per cent, although their relief is generally less than 100 feet per mile square. These have been referred to as the Lethbridge Moraine.[36]

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[36] L. Horberg, "Rocky Mountain and Continental Pleistocene Deposits in the Waterton Region, Alberta, Canada," Bulletin, Geological Society of America, Vol. 56, 1954, pp. 1093-1150.

North of these,near the Oldman River [Q17: Q18], is an extensive area of sand and gravel deposits, and much of this too has a land form of (B1) class.

The remaining large areas of land form class higher than (A1) or (A2) are all found close to the southern and southeastern border of Alberta. In the southwest is that area which, although geologically part of the foothills, is more similar to the plains with regard to land form. Many of the areas of steepest slope and highest relief correspond to bedrock outcrops. Most of the area of slopes between 5 and 10 per cent, however, has till at the surface, and a series of Moraines has been mapped in the district.[37] Much of the area immediately south of the Oldman River [M18: M19: N18], with modal average slopes varying from 5 to 20 per cent, and a local relief under 300 feet, together with the area of (B) class slopes slightly to the south [M19, centre] constitutes the Glenwoodville Moraine. To the south of this till areas of slopes between 5 and 20 per cent form the Kimball Moraine. The same Moraine includes most of the areas of higher land form class east to the Milk River Ridge. However, in many locations, bedrock appears at the surface, and often coincides with an area of higher relief. The scarp of the Milk River Ridge has already been mentioned in its northern part. At the east end, however, it swings southward, and

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[37] Loc.cit.

is again indicated as an area of slope class (D) [P20]. The area south and west of the scarp is formed mainly of till, and the associated land form of classes (B2), (C1), and (C2) suggest that much of the area is hummocky disintegration moraine.

Extensive areas of slope class (B) and (C) are present between the Milk River Ridge and the Cypress Hills; the relief is generally of class (1) or (2). As the surface material in much of the area is till, it is probable that the land form varies from one of hummocky disintegration moraine to one of ground moraine. In one district, however, local relief is greater than 300 feet per square mile [Q20, S.E.]; although the surface material is till, the high local relief is due to bedrock influence, as the area forms the foothills of the Sweetgrass Hills whose main mass lies south of the border. East of this point bedrock lies very close to the surface, and undoubtedly affects the appearance of the land form, although it is of similar slope and relief to surrounding areas.

The bedrock areas of the Cypress Hills have already been described briefly with regard to their association with areas of high local relief. Mention should be made, however, of the remarkably level summit of the Cypress Hills, which appears as an area of (A1) class. Two small areas of the same class to the south [T18,S.] correspond with remnants of the Flaxville plain as shown by Broscoe.[38] More extensive

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[38]A.J. Broscoe, "The Geomorphology of the Cypress Hills-

areas of class (A1) are associated with the Lake Pakowki basin to the southwest of the Cypress Hills [R19: S18: S19]. Most of these correspond with areas of lacustrine deposits, and suggest the former extent of the lake. Immediately north of the present lake is an area of sand and gravel deposits, where modal average slopes between 10 and 20 per cent, combined with a relief of less than 100 feet, indicates the presence of sand dunes.

North of the Cypress Hills, an area of predominantly (C2) land form class extends along the eastern border of Alberta. This is interrupted, east of Medicine Hat [Q17,N.], by a narrow valley of (A1) floor, while slightly further north a large area of similar land form represents the Many Islands Lake district [T16,E.]. However, the land form of the south-eastern edge of the plains region is predominantly of (C2) or (C1) class, and is formed of till. The area of hummocky disintegration moraine indicated by this is continuous with the southern end of the Viking Moraine.

In most instances, there is a marked contrast between the land form classes associated with the general plains surface, and those associated with the major river valleys. For the greater part of their courses, the latter are distinguished as narrow, sinuous bands of higher land form class cutting across areas of gentler slope and lower local

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Milk River Canyon Area, Alberta," Guide Book, Part 1, to the Fifteenth Annual Field Conference, Alberta Society of Petroleum Geologists, 1965, pp. 74-84.

relief. This relationship is found throughout the geological plains region, including the areas of slope steeper than 5 per cent, but to a lesser degree in the transitional zone in the west. Thus in this respect also, the area in the west is transitional. In those valleys so differentiated, slopes are steeper than 10 per cent in all but a few cases, and are frequently between 20 and 50 per cent. The depth of incision may be as great as 600 feet in some places.

Contrasts in form of the major river valleys, and between different reaches of the same valley, can be deduced. Many of the plains river valleys possess almost level floors, but these are usually too narrow or too discontinuous to be shown if the valley walls are also to be depicted. Nevertheless, as discussed earlier (p.58), it is theoretically impossible for areas of land form class (C1) and (D2) greater than $\sqrt{2}$ miles (0.09 inches) in width to represent only two slopes, and where valleys are so designated the presence of a large area of less than modal slope is indicated. In most cases, this is concentrated in the valley floor. In addition, the map shows areas where valley floors are very wide and unbroken for a considerable length. Thus portions of the North Saskatchewan [J4: K3: K4: L3], the Battle [R5: R6] and the Red Deer [O10 : O11] River valleys are so characterised. For much of its length between 111° W. and the Saskatchewan border, an exceptionally wide level area is adjacent to the Red Deer River [R13: S13: T13]; the bounding (D2) walls are in places four miles apart. At one

point [S13, N.W.], a small elongated area of (C2) class is included within the broad (A1) area, and this would appear to represent an old channel of the river.

Variation in slope of the valley walls is also indicated, but such contrasts may not be striking where adjacent slope classes are concerned. In such cases, the degree of incision may be more noticeable. That is, there is probably a greater contrast in appearance between valleys of (C1) and (C2) land form class than between those of (C3) and (D3) class. However, an observable variation in form is suggested when slopes of non-sequent classes are involved, especially where these occur in adjacent portions of one valley. For example, the Bow valley above Carseland [N13, S.W.] has slopes over 20 per cent, while below Carseland they are less than 10 per cent. The valley is also wider in this lower section, suggesting altogether that it is a less striking feature of the landscape in this area, although it is incised to the same degree.

A consideration of valleys in relation to the surrounding area also indicates contrasts between them, with reference to their prominence as features of the land form. Both the width of the valley, and its related slopes and local relief compared to those prevalent on either side, are concerned. Generally, a valley is more conspicuous locally as its width decreases, or as the contrast between the associated land form class and those on either side increases.

The Macleod valley [H2: I1] in particular differs from other major valleys in that for most of its length (within

the map area), slopes are less than 10 per cent, though they have a relief of over 100 feet. However, in its northern portion, such slopes are similar, as regards inclination and relief, to those of the surrounding plain, and the valley is therefore not too prominent a feature. Portions of other major valleys bear a similar relationship to the surrounding area, in that they are not differentiated as areas of steeper slopes or greater local relief. For example, immediately after leaving the foothills the Brazeau [I5, centre] and North Saskatchewan [K7, N.W.] Rivers both flow across an (A1) plain in undifferentiated valleys, while the same situation is present on the Red Deer River [L8], and on the Oldman River east of the Porcupine Hills [N18]. The fact that in such cases the valley is not so prominent a feature does not necessarily mean that no definite valley exists. Slopes and local relief may be slightly greater than those of the surrounding area, but either too small in extent, or the differences too small in magnitude, to affect the land form class. The latter is especially probable when a major river valley is undifferentiated in an area of (C2) class; within the class limits, slopes may be up to 10 per cent steeper, and the local relief nearly 200 feet greater.

It is noticeable that in some locations a change in valley form coincides with a pronounced change in direction.

Examples can be seen in the Brazeau, North Saskatchewan, Battle and Red Deer valleys. The Brazeau River [I5] at first flows northeastward in an undifferentiated valley of (B2) class, but beyond a sharp turn to the southeast, the valley walls increase in inclination to class (D), although to either side slopes are less than 5 per cent. The North Saskatchewan valley, at a similar change of direction [L3], narrows considerably, and the wide (A1) floor present above here disappears; the south wall of the valley is still of the same land form class, but the slope of the north wall increases from class (C) to class (D). In the first hundred miles, the Battle River follows a sinuous course, and at two points changes in direction are accompanied by marked changes in valley form. The river first flows southeastward in a comparatively well-defined valley of class (C2), compared with the surrounding (A1) plain. The river then turns and flows northeastward [M6] in an undifferentiated valley. A short distance above a 90° bend to the east [N5], however, the river becomes incised in a valley of (D2) class. Further south, the Red Deer swings from a northeasterly to a south-easterly course [M8], and once again the valley slopes increase to over 20 per cent below the change of direction, while the local relief increases eventually to over 300 feet.

In all these examples a general pattern can be discerned. The river valley is narrower, or of higher land form class, in those sections where the river flows southeastward, while

in the northeasterly flowing sections the valley includes a wider floor, or is of lower land form class. In the last three cases, the pattern can be related to effects of the Pleistocene glaciation. The Keewatin ice, or resultant deposits, blocked the northeasterly valleys in the case of the North Saskatchewan and Red Deer Rivers, diverting them to the southeast. These lower portions, of the valleys are therefore younger in age than the upstream portions, and this is reflected in their appearance. In the case of the Battle River, the course was affected by the presence of spillways formed by glacial meltwater. Thus the upper southeasterly stretch occupies one of a series of ice-marginal channels; the steep walls and flat floors of other channels are indicated, by the elongated areas of (C2) and (A1) class respectively, to the south of the Battle River [L5]. Beyond this, the ice-marginal channel is no longer prominent in the landscape [M6], and the river meanders in a poorly-defined valley in a general northeastward direction. About forty miles farther downstream, the river again follows a spillway [N5], in this case the Gwynne outlet, and is once more deeply incised in a steep-sided valley. It is probable that a similar explanation is present in the case of the Brazeau River.

No such apparent reasons can be found for many changes in form of the major river valleys. In some areas boundaries which appear on the map may not represent appreciable changes in reality. On the other hand, especially where adjoining sections of a valley are designated by non-sequent land form classes, it is possible that a specific explanation might

appear in a study of the evolution of the area.

As a rule, only the major rivers, and their tributaries immediately above the junction, have valleys distinguished by a higher land form class for any distance. In two districts, however, there are areas of similar land form class of typical narrow, elongate shape not associated with major rivers. An additional characteristic is the sub-parallel nature of the bands of higher land form class. One such district is that south of the Oldman River, between Lethbridge and Medicine Hat. Here the parallel areas of steeper slope and greater local relief represent several of the coulees typical of southeastern Alberta. At the present day these valleys are dry, or contain only small streams. They are, in fact, glacial spillways, formed by the meltwater of the Keewatin ice. The northermost is Chin Coulee [P18: Q18: R18]; this is incised from 100 to 300 feet into the surrounding plains surface, and the slopes between 10 and 20 per cent are far steeper than those prevalent to either side. Forty Mile Coulee joins this from the north [R18]. It is not so prominent a depression in its upper part, being shown as land form class (B1), but the degree of incision and the inclination of the walls both increase a short distance above the junction with Chin Coulee. The latter is continued northward in Seven Persons Coulee [R18], also of land form class (C2).

Etzikom Coulee, of similar slope and local relief, lies to the south of Chin Coulee, and runs sub-parallel to

it [P19: Q19: R19]; however, it comes to an end in the Lake Pakowki depression. A third coulee system is distinguished south of this. Verdigris Coulee [P19: P20: Q20] is also of land form class (C2), and eventually joins the present Milk River valley. At its head, Middle Coulee [P19, W.] has a similar form, while Kipp Coulee [O19, N.E.] is also a part of the system. Only the upper portion of the latter is differentiated on the map, as a band of (B2) class. This part of Kipp Coulee is therefore also incised to a depth of 100 to 300 feet, but the valley slopes are less steep than those of the other coulees, while the lower part of the coulee is not distinguished from the surrounding plain.

The second district where spillways are particularly numerous, as indicated on the map, lies north of Calgary [L10: M10: M11]. Present-day streams flow in these, but their valleys are not differentiated beyond the points where they leave the spillways. The northernmost spillway is occupied by the Rosebud River. For most of its length, the land form is of class (C2), but the relief gradually decreases, and at the southern end is of class (1), while beyond this point the spillway disappears as a prominent element in the land surface. The Rosebud River, however, continues eastward, but in a valley not significant enough to be differentiated except for the last few miles above its junction with the Red Deer [O11]. Two tributary spillways entering that containing the upper Rosebud River, from the west, are distinguished on the map; these are now occupied

intermittently by streams. Immediately to the south, Crossfield Creek [M11], though also a non-perennial stream, occupies a valley incised over 100 feet into the plains surface for much of its length. This too is a former spillway.

The spillways associated with the course of the Battle River have already been referred to. However, the position of the Gwywne outlet above the entrance point of the Battle River is indicated by an elongated area of (D2) class, while the river for many miles downstream follows the former spillway. The wide (C3) class valley of Paintearth Creek [P7: Q7] also represents a former branch of this spillway.[39]

Several minor river valleys are also differentiated for short distances, and some of these are worthy of mention as they are the most prominent feature of the land form, as indicated by the map, in certain areas, Thus the Pembina valley [J3: K1: K2] possesses steeper slopes and in places a greater local relief than the surrounding area, although the valley slopes decrease in inclination from over 20 per cent in the south to less than 10 per cent in the north. Further east, the valley of the Sturgeon River [M2: N1] interrupts a wide expanse of land of (A1) class. The river at first flows parallel to, and a few miles north of, the North Saskatchewan; the valley slopes here are for the most part

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[39]L.A. Bayrock, Glacial Geology, Alliance-Brownfield District, Research Council of Alberta, Preliminary Report, Geology, 57-2, 1958, p.13.

of the order of 5 to 10 per cent, but the river is from 100 to 300 feet below the surrounding plain. A few miles downstream [N1], however, the river suddenly turns to the southeast, and at this point the valley becomes much narrower, and the valley slopes increase to over 10 per cent.

Although in most cases where the river valleys of the plains region are differentiated it is by virtue of possessing significantly steeper slopes than the surrounding area, this is not always so. Ribstone Creek, for example is distinguished in its upper course [R8] by a (C1) class valley, but beyond this it is the wide (A1) class floor which proves the most significant characteristic of the valley. The valley walls in this section have an inclination and relief of the same land form class as the interstream areas. The Sounding Creek valley shows a similar pattern, in that in its upper course [S10] it, and several tributary valleys, are distinguished as (B2) and (C2) areas, while further downstream a broad (A1) area flanks the creek for many miles [T8: T9: T10]. Further west, at the same latitude, the markedly flat floor of Big Valley Creek [O8: O9] is a prominent feature of the land surface.

Most minor river valleys are not differentiated throughout their length, but in some areas, widely separated portions of the same valley may be distinguished. Such is the case with regard to the valley of Berry Creek. The upper portion

appears as a short stretch of (C1) class [Q10]; the valley walls here have an inclination of 10 to 20 per cent, compared to a modal average slope of less than 5 per cent in the surrounding plain. Below this stretch, the valley is for some way undifferentiated, although two elongated areas of (B2) class [Q11] actually mark the walls of the valley. Although the local relief of the walls is greater here, the valley is very wide, and is therefore not so prominent as one unit. Further downstream, however, the valley becomes markedly incised in the plain, as indicated by a narrow, elongated area of (D1) class [Q12]. Beyond this the valley is not distinguishable until immediately above the junction of Berry Creek with the Red Deer River [Q13].

A noticeable feature is that, south of this latitude (51° N.), with the exception of the major rivers and spillways already discussed, the only valleys differentiated on the map occur immediately east of the foothills or in the areas south of the Milk River Ridge and the Cypress Hills. The most important of these are the Waterton, Belly and St. Mary valleys. The Waterton valley is distinguished as a narrow band of (C2) class [M19: N19]. Although the upper part of its course is in the geological region of the foothills, with regard to land form the immediate area is more akin to the plains, and characteristically the area of higher land form class is associated with the river valley. The Waterton joins the Belly River, but for most of its length in the plains the valley of the latter is not

differentiated. Its upper course may be seen in the elongated, south to north band of (C2) class [M20]. While in the south this represents a typical foothills valley, in that adjacent areas are of higher land form class, to the north the situation is reversed, and the river is incised below areas of gentler slope or lower local relief. Slightly further north, the valley is differentiated, for a short distance as an area of (B2) class [M19; S.E.]. From this stretch to just above the junction with the Oldman River [M18: N18], however, the valley is not distinguished as a whole, although a high, steep portion of its east bank is represented by an area of (D2) class [N19]. The St. Mary River, in contrast, flows in a well-defined valley throughout its course [N19: N20: O18: O19]. In its upper plains portion, slopes vary from 5 to 10 per cent, but below this, they are continuously steeper than 20 per cent. The valley has a relief of over 100 feet throughout its length, and this increases to over 300 feet immediately above its junction with the Oldman valley.

In the area south of the Cypress Hills portions of several valleys are differentiated on the map. The most noticeable is the valley of Lost River [S20], which has a land form of (C2) class. At its northern end, however, this becomes the valley of Canal Creek, which flows northward into Lake Pakowki, and which has a wide level floor, of (A1) class in its lower reaches. To the east a similar situation occurs in the valleys of Bullshead and Medicine Lodge Creeks,

distinguished by three isolated elongate areas of (B1) class on the map [T18: T19]. The northernmost of these represents the valley of Bullshead Creek, in which the creek flows north, while the other two represent wider stretches of the Medicine Lodge valley, in which the creek flows to the south. In the last four instances, it is the valley floor which is significantly different from the surrounding area with regard to slope and local relief.

In addition to the examples specified above, numerous other valleys are differentiated for short portions of their length. In most cases, they can be recognised as narrow, sinuous areas of steeper slope, and often greater local relief, bearing little relationship to the land form of the surrounding areas.

Summary

The plains region is distinct in possessing large areas of modal average slope less than 5 per cent. However land form classes (B1), (B2), (C1), and (C2) are also typical of the region. It is possible that several areas of (B1) class may depict a characteristic "plains" land form. Class (C1) is anomalous with regard to the definitions discussed earlier; slopes are very steep for a "plains" land form, but the local relief is lower than that usually associated with "hills." Areas of class (B2) or(C2), however, probably indicate districts of "low hills" within the plains region. Several of these are prominent enough to have been so named topographically, while, in gmneral, those areas of slope

greater than 5 per cent have been recognised as Moraines, sometimes end moraines, by glacial geologists or in soil reports. In addition, areas of local relief greater than 300 feet per square mile, usually in association with modal slopes steeper than 10 per cent, are present in several parts of the region, but are especially prominent in a transitional zone between the foothills boundary and the typical plains land form. These all represent areas of "hills" within the geological region of the plains. Many of the areas of both "low hills" and "hills" correspond with the surface expression of bedrock. Farvolden has stated that, in general:

> the present day surface is coincident with the bedrock surface over most of the southern half of Alberta. The major upland areas are underlain by bedrock. . .[40]

No such pronounced trend as that apparent in the mountains and foothills is present in the pattern of distribution of the land form classes of the plains region, but, east of longitude 114° W., districts of modal slope steeper than 5 per cent are concentrated in three bands. One lies between latitudes 53° 30' N. and 50° N., and runs approximately north to south between longitudes 112° 30' W. and 113° 30' W. in the north, and 112° W. to 113° 30' W. in the south. A second is adjacent to the eastern border of Alberta, and its width varies from a maximum of eighty miles to only thirty miles at latitude 51° 45' N. In the

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[40] R.N. Farvolden, "Bedrock Channels of Southern Alberta," in, Early Contributions to the Groundwater Hydrology of Alberta, Research Council of Alberta, Bulletin No. 12, Edmonton, 1963, pp. 63-75.

south, this area is continuous with a third district of steeper slopes along the southern border of Alberta. The latter area includes the prominent Milk River Ridge and Cypress Hills scarps.

In nearly all parts of the plains region, the major river valleys, and some minor valleys, are distinguished as narrow areas of steep slope and comparatively high local relief, and in many cases, are the most prominent feature of the plains land form.

Summary and Conclusions

The land form of southern Alberta is characterised by a wide range of values of both modal average slope and local relief per mile square. There is a pronounced concentration of areas of steep slope and high local relief in the west, while gentler slopes and a lower local relief prevail over the larger, eastern part of the area.

In the far west, all but a few districts have modal slopes steeper than 20 per cent, and a relief greater than 1,000 feet per mile square, and large areas of slopes steeper than 50 per cent, and in places steeper than 100 per cent, and relief greater than 2,000 feet per mile square, represent mountain ranges. The eastern limit of this land form type corresponds generally with the eastern geological boundary of the mountain region, and in most latitudes, there is a well-defined mountain front.

At the opposite extreme is the plains region of the east. However, in this area, there are frequent anomalies between the form of the land, and the designation of the area as a "plains" region. Generally, slopes are less than 20 per cent, and local relief is under 300 feet per mile square. A surprisingly large area has modal slopes between 10 and 20 per cent. While such slopes are not steep compared with those prevalent in the mountain region, they would not be accurately described as "gentle". The low local relief means, however, that such steeper slopes are comparatively short in

length, and though they may be conspicuous at close quarters, they are not so prominent in a more distant view. Land forms of classes (C1) and (C2) are a distinctive feature of the plains region of Alberta, in that they would commonly not be envisaged in a general conception of a "plains" area. The descriptive term "flat" frequently applied to the area would appear, in several districts, to refer to the absence of high local relief rather than to the actual inclinations of the land surface.

Many districts of class (B2) or (C2) represent "low hills" present within the plains region, while several areas have a relief greater than 300 feet per mile square, and modal slopes steeper than 10 per cent, and would be classed as "hill land". The "hill land" areas in the districts of the Milk River Ridge and the Cypress Hills are quite extensive, but they are separated from the general area of steeper slopes in the west, and thus form local "hills" within the "plains" area. Other isolated areas of "hill land" can be similarly described. However, in the west of the plains, north of latitude 49° 40' N., "hill land" is present immediately east of the geological boundary of the foothills, and it is suggested here that this forms a transitional zone between the typical foothills and the typical plains land forms. In the far north, this zone is very wide, and includes extensive areas where the relief is greater than 600 feet per mile square to either side of the Athabasca River. A similar high local relief characterises the land form of the

southern part of the zone, in the Porcupine Hills area. The foothills, as geologically defined, commonly have slopes steeper than 20 per cent, and a relief greater than 600 feet per mile square, increasing, in many areas, to over, 1,000 feet per mile square in the west, and where there are prominent ridges further east. They therefore have comparatively steep slopes and high relief for a "hill land" area.

South of latitude 49° 40', however, an association of land form types characteristic of the plains and the transitional zone further north extends west to the mountain boundary, and includes only a few districts of locally steeper slope and greater local relief.

The western area of steep slopes, corresponding to the foothill and mountain regions, is further characterised by a pronounced trend, varying from northwest to southeast in the north to north to south in the south, in the distribution of different land form areas.

Throughout southern Alberta, the major river valleys have associated slopes and local relief which contrast markedly with those prevalent in the surrounding areas. In the mountain and foothill regions, they are prominent as areas of gentler slope and lower relief, whereas in the typical plains the rivers are commonly incised, and the valleys form areas of steeper slope and higher local relief. In the transitional zone, however, examples of both types of valley are present.

No indication of absolute elevation is given on the

map; this could best be added by means of spot heights, but at the risk of making the map illegible. Numerous maps showing elevation exist for the area, and the omission is not serious with regard to primary features of the land form when the map is viewed as a complement to these. In considering the major secondary or local features of the land form local differences in elevation, rather than absolute elevation, are important in determining their general appearance in the field, and these are indicated to some extent by the local relief value. However, the lack of absolute elevation or slope direction data means that, while the local amount of change in elevation can be estimated, the direction of change cannot. Thus a narrow steep-sided valley cannot be distinguished from a narrow steep-sided ridge in most cases. As far as possible, such contrasts have been indicated in the text.

A large degree of generalisation (with reference to both the value of the elements of land form, and to the delimiting of areas wherein the values are similar) is involved in producing, at this scale, a map of a phenomenon as variable as the form of the land surface. Nevertheless, the map depicts both explicitly and implicitly, and in some detail, the variation of several characteristics of land form in southern Alberta. These characteristics (inclination and possible maximum length of prevalent slopes, and the change in elevation per mile square) are those which, in large

part, determine the general appearance of the land form. Although classifications based on genesis or structure would in some instances serve equally well in differentiating land form types, this is not always the case, and it is suggested that the characteristics mapped are commonly of more direct consequence in a geographic study of the region.

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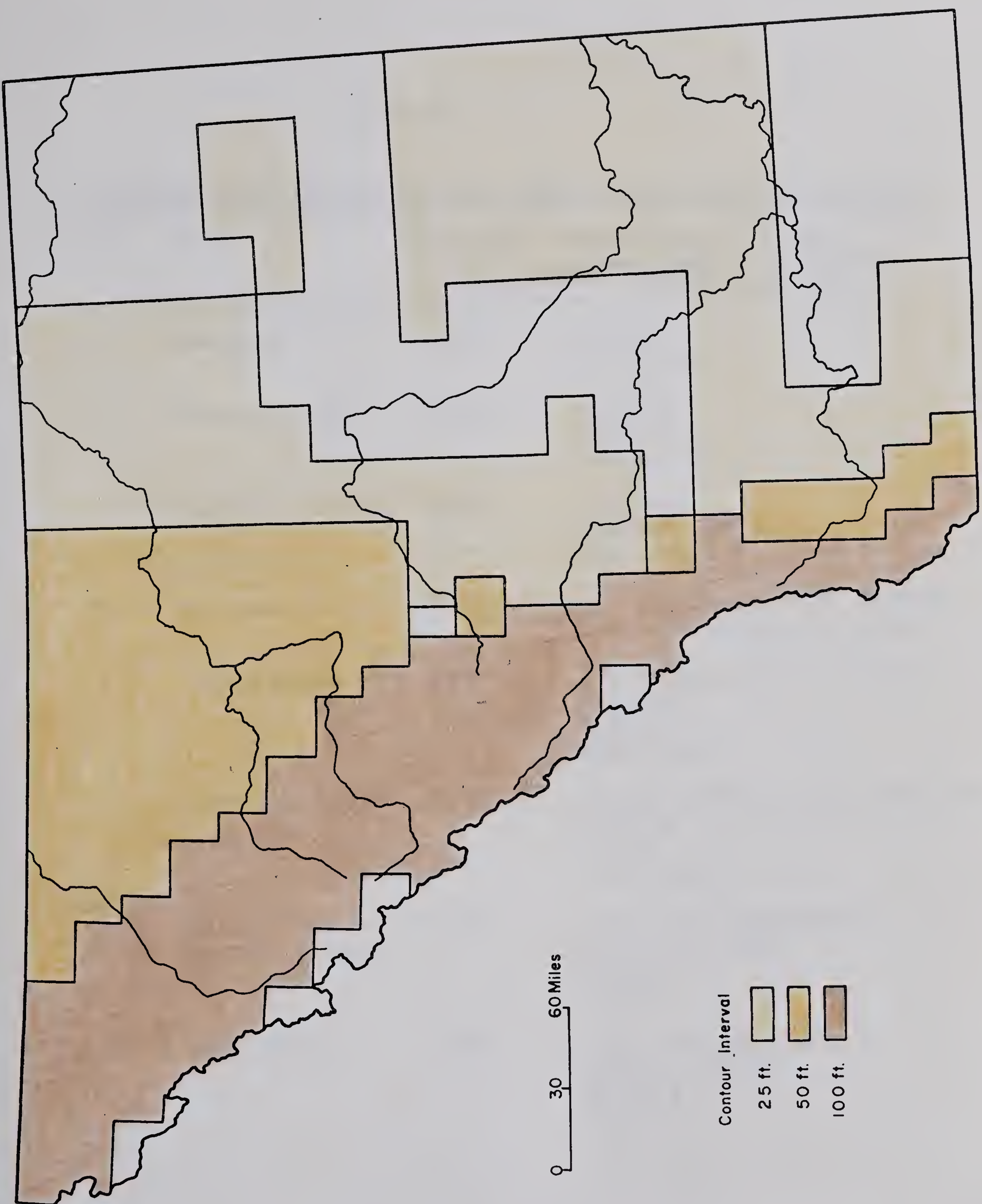
APPENDIX A



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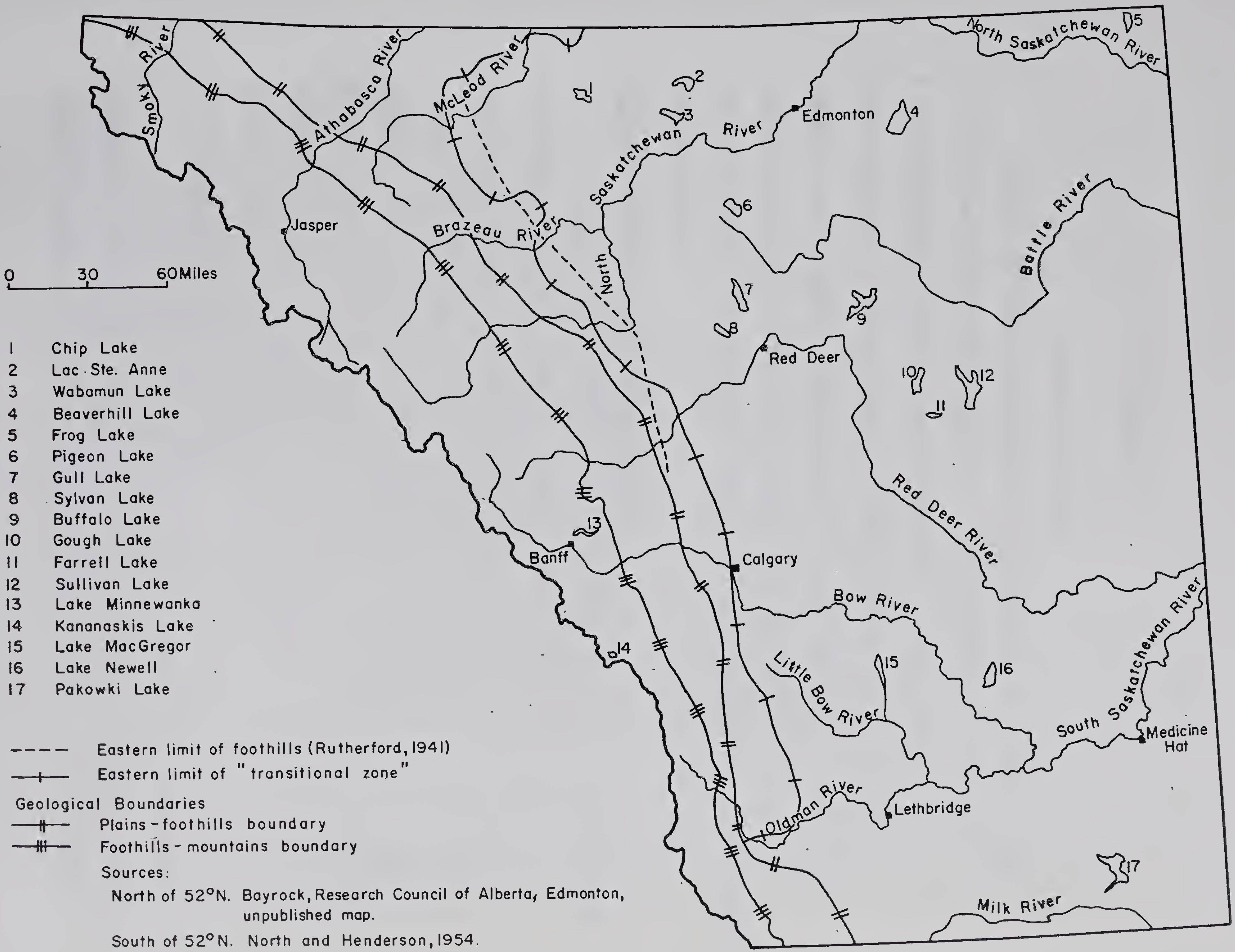
APPENDIX B

ALBERTA SOIL SURVEY REPORTS USED IN COMPILATION

No.	Name	Published	Topography Classes (and other topographic information)
1	Macleod	1925	hilly sand dunes
2	Medicine Hat	1926	rolling hilly sand dunes
3	Sounding Creek	1927	rolling heavily rolling sand dunes
4	St. Ann	1930	rolling to heavily rolling heavily rolling to hilly
7	Rainy Hills	1937	level and gently rolling rolling hilly sand dunes
8	Sullivan Lake	1938	gently rolling and undulating rolling hilly sand dunes
9	Lethbridge and Pincher Creek	1939	level and undulating gently rolling rolling hilly
10	Milk River	1941	level and undulating gently rolling rolling hilly

No.	Name	Published	Topography Classes
11	Blackfoot and Calgary	1942 (revised 1960)	level and undulating gently rolling rolling hilly
12	Rosebud and Banff	1943	level and undulating gently rolling rolling hilly
13	Wainwright and Vermilion	1944	level and undulating gently rolling rolling hilly
14	Peace Hills	1947	level and undulating: $<4\%$ gently rolling: 4-8% rolling: 8-15% hilly: $>15\%$
16	Red Deer	1951	level and undulating: $<5\%$ gently rolling: 5-9% rolling: 10-15 % hilly: $>15\%$
19	Rocky Mountain House	1957	level and undulating: $<4\%$ gently rolling: 4-8% rolling: 8-15% hilly: $>15\%$
21	Edmonton	1962	level and undulating: $<5\%$ gently rolling: 5-9% rolling: 10-15% hilly: $>15\%$

APPENDIX C



Physiographic regions, and major rivers, lakes and towns of southern Alberta.

APPENDIX D

GLACIAL GEOLOGY

Most of the area mapped was covered by glacial ice during the Pleistocene Period. The results of glacial deposition and erosion are therefore of importance in considering the land form of southern Alberta, from both genetic and generic standpoints, since glaciation modified the pre-existing land form to a great extent, and many of the terms used to describe the resulting landforms have generic connotations.

A Brief Summary of Glacial History

Alberta was affected by ice from two distinct sources, involving what are often considered as two different, or even contrasted, forms of glaciation. The greater part of the province, that lying to the east of the Rocky Mountain system, was covered by the Laurentide Ice Sheet, and thus experienced continental glaciation. The Rocky Mountains and foothills were glaciated by Cordilleran Ice, and show the effects of valley or Alpine glaciation.

The Laurentide Ice Sheet

The Laurentide Ice Sheet covered all of Canada east of the Rocky Mountains. The portion of it affecting Alberta centred around the Keewatin ice-divide, which was situated

about 200 miles inland from, and approximately parallel to, the present northwestern shore of Hudson Bay.[1] Thus the ice advanced in a generally southwesterly direction across the province, but the many secondary lobes and local readvances resulted in specific directions of movement varying from southwestward to southeastward.[2] Radio-carbon dates indicate that the last major Keewatin ice advance in Alberta occurred earlier than 31,000 B.P., and ice remained at least until 11,000 B.P.[3] Retreat of the ice front was towards the northeast, and was accompanied by large-scale downwasting and stagnation.[4] At the glacial maximum, Keewatin ice may have reached a thickness of 5,000 feet over the Edmonton area;[5] deposits exist at altitudes of 4,200 feet northwest of Calgary, and at 4,100 feet on the north side of

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[1]C.H. Stockwell (ed.), Geology and Economic Minerals of Canada, Geological Survey of Canada, Economic Geology Series No. 1, Ottawa, 1957, p. 464.

[2]Opinion is divided on the general direction of ice advance. See C.P. Gravenor and L.A. Bayrock, "Use of Indicators in the Determination of Ice Movement Direction in Alberta," Bulletin, Geological Society of America, Vol. 66, 1955, pp. 1325-1328; and a discussion, and reply, of the above in Bulletin, Geological Society of America, Vol. 67, 1956, pp. 1101-1110.

[3]C.P. Gravenor and L.A. Bayrock, "Glacial Deposits of Alberta," in R.F. Legget (ed.), Soils in Canada, Royal Society of Canada Special Publication, No. 3, 1961, pp. 33-50.

[4]Loc. cit.

[5]Pers. Comm., L.A. Bayrock, Research Council of Alberta, Edmonton.

the Cypress Hills.[6]

The Cordilleran Glacier Complex

At an early stage in the Wisconsin glaciation, ice caps formed on the Rocky Mountains, and discharged westward, and eastward over southwest Alberta.[7] The ice caps expanded until, at the glacial maximum, they coalesced with ice from the Coast and Cascade Mountains of British Columbia to form the Cordilleran Ice Sheet, whose axis of outflow was in Central British Columbia.[8] The ice divide had therefore shifted westward, and the eastward discharge of the Ice Sheet flowed through the Rocky Mountains. Remnants of the Pleistocene ice caps still exist on the Rocky Mountains.

The Laurentide and Cordilleran Ice Sheets coalesced east of the Rocky Mountains, although some areas may have been left unglaciated between the two.[9] Ice from the mountains did not extend very far eastward; even at its maximum it probably reached no further than fifty miles from the mountains in southern Alberta, and sixty miles in the latitude of Edmonton.[10] Some topographic highs in southern Alberta remained unglaciated; of these, the Cypress Hills and

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[6]Gravenor and Bayrock, "Glacial Deposits of Alberta," op.cit.

[7]R.F. Flint, Glacial and Pleistocene Geology, New York, 1957, p. 303.

[8]Ibid., p. 305.

[9]Glacial Map of Canada (scale 1: 3,801,600), The Geological Association of Canada, 1958.

[10]Flint, op.cit., p. 306.

the Porcupine Hills are the most prominent.

Features Resulting from Glaciation

The intention is to explain briefly terms used in the text. Those referring to landforms produced by Alpine glaciation are widely known and accepted, and are therefore not included. This section is not a comprehensive list of landforms resulting from glaciation, or of terms synonymous with those used. Although some names imply a particular mode of formation, genesis of the landform is not the main concern, and is not discussed in most cases. However, terms referring to the materials of which the landforms are composed are included.

Glacial Deposits

Glacial Drift: embraces all rock material in transport by glacial ice, all deposits made by glacial ice, and all deposits predominantly of glacial origin. The term drift therefore includes till, stratified drift and rock fragments.[11]

Till: glacial drift predominantly not sorted according to grain size. The composition may vary widely. It is a direct glacial deposit, although some water sorting may have occurred in some instances.[12]

Moraine: an accumulation of drift having a constructional topographic expression in detail that is independent of the surface underneath it, and having been built by the direct action of glacier ice.[13] The term is, however, sometimes used as a synonym for till, and is not restricted as above.

Stratified Drift: glacial drift sorted by size and weight, and therefore deposited by water or air.[14]

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[11] Ibid., p. 108. [12] Ibid., p.109. [13] Ibid., p.130. [14] Ibid., p. 109.

Till Landforms

Ground Moraine: is ideally composed of till thick enough to mask the underlying topography, but the term is often applied also to areas where the till cover is thin. The landform is one of knobs and intervening depressions, the latter often containing lakes or swamps. Relief (of individual knobs) is low, and is defined in Alberta as being less than ten feet;[15] slopes are rarely steeper than 5 per cent. No pronounced linear pattern is apparent.

Hummocky Disintegration Moraine: is also a till landform of knobs and lake-occupied or marshy depressions, but the relief (of individual knobs) is over twenty feet,[16] and slopes are commonly steeper than 10 per cent. Stalker estimates that the relief of some ridges may be as great as seventy feet, and that the steepest slopes usually range between 21 and 47 per cent.[17] A linear pattern is often displayed; this may be formed by rows of knobs or by continuous till ridges, which are commonly sub-parallel. More than one set of such linear elements may be present, forming a diamond-shaped pattern. Despite the greater regularity of such features, however, the general impression in the field is still one of choppy, irregular topography.

[15,16] Pers. comm. L.A. Bayrock, Research Council of Alberta, Edmonton

[17] A. MacS. Stalker, Ice Pressed Drift Forms and Associated Deposits in Alberta, Geological Survey of Canada, Bulletin 57, Ottawa, 1960, pp. 20-21.

<u>Intermediate Moraine:</u> is intermediate in appearance between ground moraine and hummocky moraine, and the three therefore form a gradational series with regard to land form. Intermediate moraine is thus defined as having a relief (of individual features) between ten and twenty feet. The features are generally similar to those described above but linear elements are, theoretically, less conspicuous than in areas of hummocky moraine.

<u>End Moraine:</u> is impossible to define without reference to genesis, since its form may vary widely.[18] It is a ridge of till built along the terminal margin of a glacier, where relative standstill of the ice front resulted in greater deposition over a small area. Its features are often similar to those of hummocky disintegration moraine, and the same landform might be designated by either term depending on the point of view of the observer. In theory, an end moraine should be distinguishable by its ground plan; this should be long compared to its width, and often lobate. In practice, however, so called end moraines are often discontinuous.

<u>Features Produced by Glacial Meltwater</u>

The above features are a result of direct glacial action. Glacial meltwater was also important in shaping the landforms of the plains region, and the associated terms are discussed below.

<u>Glacio-Fluvial:</u> is used to refer to streams of meltwater,

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[18]Flint, <u>op.cit.</u>, p. 133.

and to the depositional and erosional features they produced. Glacio-fluvial action was effective both within and beyond the ice-limit at any one time.

Outwash: refers to deposits of stratified sand and gravel. The form and extent varies, depending on the conditions of deposition.

Kame: is a hillock, varying in size, formed of gravel and sand.

Kame Moraine: is an area of numerous kames. The surface form is similar to that of hummocky disintegration moraine, but the surface material is gravel and sand, in contrast to till.

Spillway: is a well-defined valley, formed by meltwater, and frequently unrelated to the present drainage. Spillways may be up to a mile in width, and are typically deeply incised, with walls of greater than 10 per cent inclination, and flat, though narrow, floors. They may be several miles long. Some spillways contain outwash deposits, while many are poorly drained, and include elongated lakes or marsh.

Ice Marginal Channel: is a type of spillway, differentiated by its origin, as it is limited to those features formed by meltwater flowing along, and parallel to, the ice margin. Individual ice marginal channels therefore possess the same form as spillways, but they are often shorter in length and discontinuous in nature.

Stream Trench: is also similar in form to a spillway.

However, several stream trenches often form an intricate network of interconnecting channels, and a comparatively larger area may have slopes steeper than 10 per cent.

Ice Marginal Lake: was formed when meltwater was ponded up against the margin of the ice. The size and life-span of such lakes varied within wide limits.

Glacio-Lacustrine Deposits: are stratified deposits of clay and silt, bordered or underlain by coarser sands.

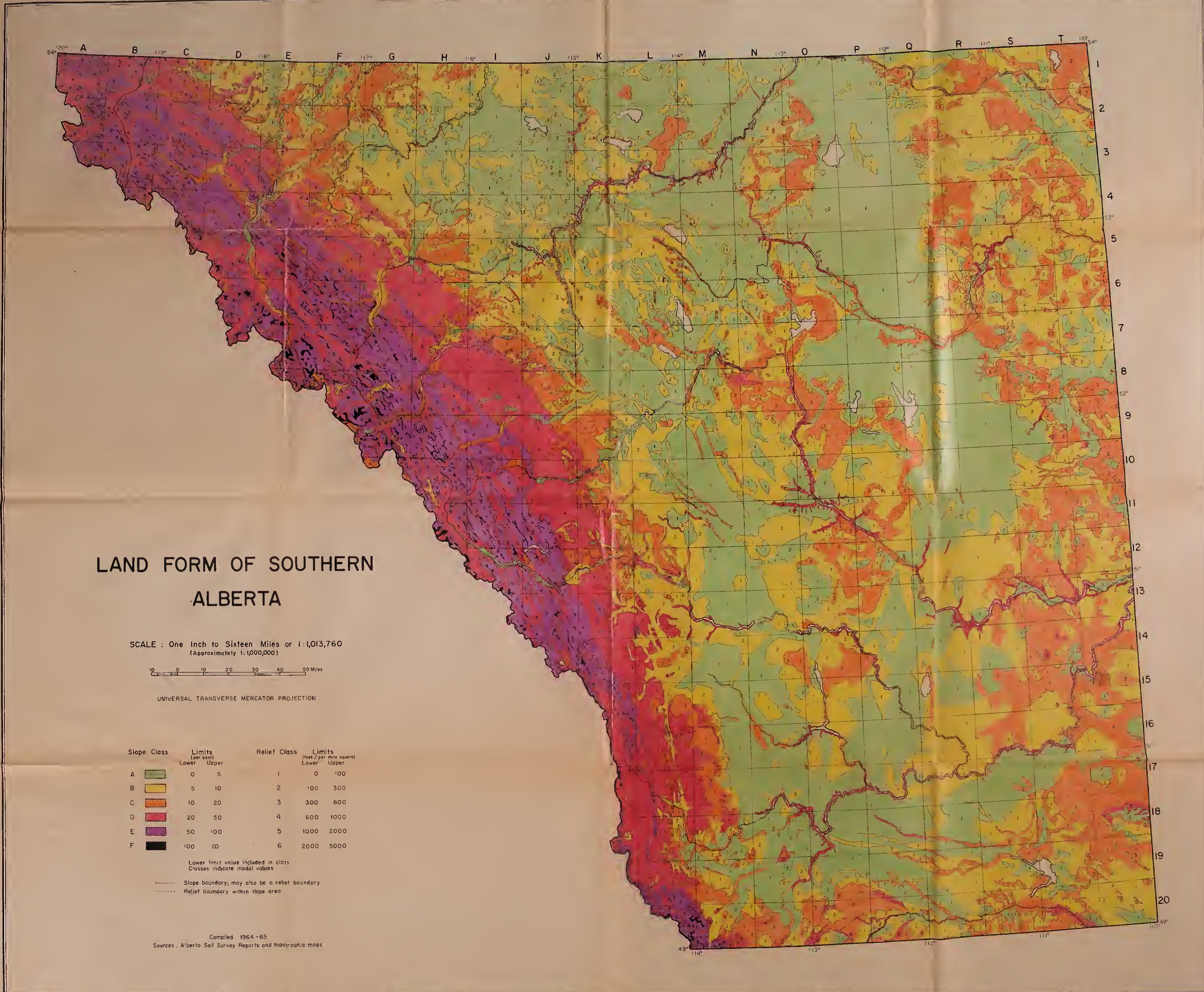
Lacustrine Plain: is an area of gentle slopes and low relief. Inclinations are usually less than 2 per cent where the lacustrine deposits are thick, but may be greater where they form a thin veneer overlying till.

Other Features

Aeolian reworking of sandy glacial (and pre-glacial) deposits was an indirect consequence of glaciation whose effects are apparent in the present land form.

Sand Dunes: vary in shape and size, but commonly have slopes steeper than 10 per cent.

Aeolian Sand Plain: also varies with regard to land form, but slopes are usually less than 10 per cent. However, individual steep-sided dunes may occur.


LAND FORM OF SOUTHERN
ALBERTA
SCALE : One Inch to Sixteen Miles or 1:1,013,760
(Approximately 1:1,000,000)
10 0 10 20 30 40 50 Miles
UNIVERSAL TRANSVERSE MERCATOR PROJECTION
Slope Class
Limits (per cent) Lower Upper
A 0 5
B 5 10
C 10 20
D 20 50
E 50 100
F 100 ∞
Relief Class
Limits (feet / per mile square) Lower Upper
1 0 100
2 100 300
3 300 600
4 600 1000
5 1000 2000
6 2000 5000
Lower limit value included in class
Classes indicate modal values
Slope boundary; may also be a relief boundary
Relief boundary within slope area
Compiled 1964-65
Sources . Alberta Soil Survey Reports and topographic maps